

HOUSING DESIGN IN EXTREME HOT ARID ZONES WITH SPECIAL REFERENCE TO THERMAL PERFORMANCE

SAMI ELAWA



**DEPARTMENT OF BUILDING SCIENCE, LTH,
UNIVERSITY OF LUND, SWEDEN, 1981**

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by Sami Elawa

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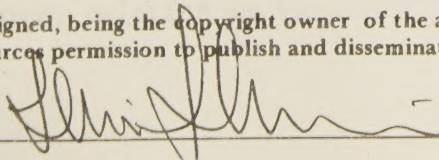


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Abstract			
In north Africa an extremely hot and arid zone covers a belt between 20° and 30°N latitude. Aswan in Egypt is a typical place with this extreme climate. Climatic modification by the building itself is one of the most important conditions for survival. In order to find a suitable design strategy for housing within the extremely hot and arid zone, especially in Egypt, two approaches are used. Firstly the old islamic building tradition in Egypt is examined and secondly Parameter studies together with model studies in wind-tunnel are carried out. As a basis for the parameter studies a building (room) was chosen, in which wall and roof construction, colours and shading of outer surfaces, window size and orientation as well as ventilation mode and rate were changed. As a result the following design strategies were found: 1. Use ventilation during night and no ventilation during day. 2. Use shaded windows facing normal wind direction or wind catches for night ventilation by natural wind. 3. Use indoor thermal capacity to store the night cool to the following day. 4. Use outside white colour or shading to prevent absorption of solar radiation. 5. Use thermal insulation to prevent heat penetration through walls and roof.			
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PREFACE AND ACKNOWLEDGEMENTS

Climatical conditions compel the designer to find an architectural solution to serve man and the comfort of his existence. Man's comfort is measured by the extent to which his physical environment should be controlled in trying to gain benefit from natural conditions to achieve a better indoor climate. It is expected that the architect should design the shelter in such a way as to bring out the best of the natural possibilities.

Architects are trained to design buildings which can fulfill certain required functions while giving full consideration to all site and environmental conditions. Building in hot climates inevitably brings the additional problem of adequate cooling, which can certainly be solved by mechanical means, but at a cost in initial installation, in operating expenses, and in maintenance costs. Mather (1974) has pointed out that "Buildings designed to work with existing environmental conditions not only cost less to operate but may even provide more livable conditions naturally."

However, it is expected that the architect will design a building in such a way as to combine maximum advantage from the natural possibilities for climatic comfort with maximum economy. In particular the world today faces a group of new factors which can be summed up as the continuous increase in the population, rapid industrial development and world-wide awareness of the necessity of finding the lowest permissible standard of human requirements.

On the one hand, the natural resources which can aid us to achieve comfort are limited. On the other hand, human life on Earth began in north-east Africa because of the moderate climate in this area, and man has lived there with an absolute minimum of cultural equipment. (Wulsin, 1949).

Throughout history man has striven to erect shelters that fulfill basic needs relating to his survival, shelter that provides an environment

favorable to his physiological and psychological requirements. During his years of effort to achieve that environment, many local variations in dwellings evolved. Among these are the old traditional houses.

My interest in this type of house goes back to the day when I practiced architecture in Cairo. There most contemporary buildings, especially multi-storey houses, are built without regard to the climatic characteristics of the area; they are instead imitative of other cultures, or represent a static evolution embodying aggregations of errors perpetuated without critical examination. But old traditional houses are built with consideration to the climatic conditions. I paid more attention to these houses especially when I lived in such traditional houses in Cairo and Libya and measured the indoor temperature and analyzed the main elements of these houses, which are designed both to react to the extreme hot climate and to satisfy other aspects which are social or religious. But many contemporary houses in the area are built in simple repetition of what has already been done, without a basis in study of different aspects of the houses' functions. Therefore the houses become malformed and ignore the issue of climatic conditions.

This study focuses on man, climate and shelter. The dissertation is divided into four parts: part one focuses mainly on the climatic conditions of the arid zone, with the climate of Egypt as an example. Part two deals with biology, analyzing the bioclimatic impact on man, classifying his needs and showing how he adapted physiologically to hot climates. Part three discusses shelter, the man-made environment and how it provides the necessary limits through analysis of the old traditional buildings and their relation to climatic conditions. It shows how these houses were adapted to the climate and obtained natural comfort in the indoor climate. Part four is a sensitivity study, testing the elements of the houses according to the methods found in traditional buildings and evaluating them according to the new technology used to obtain a better natural climate. This part also includes wind-tunnel tests on air movement in a building affected by natural wind. Lastly the conclusions are presented.

I am indebted to several persons for the completion of this dissertation.

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Sami Elawa

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Table	Caption
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Table	Caption
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1 THE PROBLEM AND THE METHOD OF SOLUTION

1.1 THE PROBLEM

Man has to modify the ambient climate in order to make it possible to obtain reasonable living conditions. In extreme climates, such as very cold or very hot climates, man has built shelters to protect himself against the outdoor climate. In cold climates, heat can be added to raise temperatures by burning available fuel. In hot climates man must use the shelter itself for the climate modification. In older days there was no possibility to cool a building by mechanical equipment; in the present day cooling equipment is not desirable in normal residential buildings in hot climates.

The building tradition in hot climates is obviously a source of knowledge about climate modification in this climate. In old traditional houses, local materials are often combined with suitable design of the houses in order to obtain a good shelter against the outdoor climate.

It may be necessary to point out here that our interest in the past is not mixed with any romantic thought or desire to keep old values. In old traditional housing there are ingenious solutions which can be evaluated and developed in order to produce a suitable indoor climate. Bechtel and Wheel (1978) have stressed that in present research "too few attempts are being made to examine the best of the old techniques and to decide where these can be applied to current human conditions; a comprehensive approach to the behavioral problems of living in arid lands is still lacking".

Man's objective is to make the inner environment equal to, or bring it closer to, his comfort zone or acceptable range. Thus one might emphasize the need for an interface between the outer environment and Man's ambient indoor environment. The problem faced in this study is to create an interface which can keep the inner environment within the comfort zone without the aid of mechanical apparatus. This interface serves as an environment control by natural means, often called passive

environmental control.

The interface chosen for study here is the building components of a house denoted by walls, roof, floor and windows.

1.2 THE METHOD

The objective of the method is to examine the effects of design variables on the internal temperature both by examining the old methods of construction, which were used to counteract the external heat in order to achieve indoor comfort and by theoretical and experimental studies using computer calculations. The method will be used to give lines to the architect which enable him to manipulate the variables until a design is achieved that is thermally suitable.

In a hot, arid zone Man can face extreme conditions of weather: high day temperature, low night temperature, hot summers and temperate winters. However, the weather for most of the year is hot and the exclusion of heat from buildings is a major problem. To provide comfort in such climates, Givoni (1974) says that "Buildings must be adapted to summer conditions, as in general the winter requirements will also be satisfied by a building in which comfort is insured for the summer". Therefore theoretical studies have been based on the summer climate.

Ancient Egyptians hated the cold and greeted the warmth of the rising sun. However, they avoided the blistering desert sun and welcomed the prevailing breeze, which was worshipped as a minor deity (Wilson, 1951). Fathy (1973) emphasizes also that "The main factor governing people's comfort inside the house in upper Egypt is air movement".

The room has been defined as a shelter, the contents of which are unknown to us. Its behaviour is discovered merely by studying the relationship between the input and the output, and not by considering what happens inside the shelter. By studying this relationship (input-output), one can learn what changes are needed in the shelter in order to achieve a given change in output, and thus information is obtained that is required to control the indoor climate of the shelter.

If, in theoretical studies, one considers the input as the surrounding microclimate (i.e. air temperature, solar radiation etc.) and the output as the indoor thermal climate, the shelter is the moderator if heat is not added and extracted from the shelter. By testing different designs of the shelter we can increase our knowledge about how to achieve a suitable indoor climate.

Several variables of the shelter are involved in the climatization process. In order to increase our knowledge two methods have been applied. The first is used to calculate the indoor temperature by computer, which is called a sensitivity study. The second is used to study experimentally the air-flow pattern inside the room.

A mathematical simulation and computer calculation has the advantage of permitting one to test different variables and to compare them to each other under chosen climatic conditions. By using this computer model I have tested more than 1000 variations, which would be nearly impossible or very expensive to do by field studies. Finally I would like to emphasize that these calculations have been carried out for the conditions of the hot, arid zone at Aswan. The calculations can be applicable for areas which have the same climate as Aswan town, as seen in the map in Figure 2.2.1.

2 THE CLIMATE

Distribution of land and sea masses produces large variety of climate. However, Koenigsberger and Ingersoll (1974) have pointed out that "Certain zones and belts of approximately uniform climates can be distinguished". Straaten (1967) has mentioned that the need for classifying climates specifically in relation to building design has often been expressed, implying that this would offer a satisfactory solution to the problem of design for climate. This means that if the earth's surface was classified into climate regions and the materials were available locally, all buildings within a particular climate zone or region could be designed similarly from a functionalistic point of view.

In this chapter I will give a general classification of climate and its zones, by specifying certain characteristics of the dry climate and concentrating on the extreme arid zone, taking Egypt as an example.

2.1 CLASSIFICATION OF CLIMATES WITH RESPECT TO BUILDING DESIGN

The purpose of any classification system is to obtain in some way an efficient arrangement of information in a simplified and generalized form. Several attempts have been made to classify the climate, the first time by the ancient Greeks, who made the classical division of the earth into torrid, temperate and frigid zones. These zones are based on solar illumination. They obviously have important temperature differences, but do not take into consideration other primary elements, such as precipitation (Miller, 1950).

Barry and Chorley (1971) mentioned that the numerous schemes for the relationship between the climatic limits to vegetation groups are based on two criteria, the degree of aridity and of warmth. The degree of aridity is determined by the "effective precipitation", which means the precipitation minus evaporation. Precipitation and temperature play the major roles in differentiating the climatic zones and Köppen classification is the prime example. According to Trewartha (1968),

Köppen classification "has outstanding merits demonstrated by its widespread acceptance for more than four decades". Rumney (1968) has also mentioned that "Wladimir Köppen did a reasonable scheme of climatic classification appear. Since then a great many systems have been presented, most of them based in some way upon Köppen's work".

The Köppen classification is based on annual and monthly means of temperature and precipitation. The effectiveness of precipitation in plant development and growth depends not only upon the amount of precipitation, but also upon the intensity of evaporation and transpiration, by which processes water is lost from soil and plants. (Strahler, 1968 and Trewartha, 1968).

Trewartha (1968) said that the Köppen classification recognizes five major groups of world climate; they are A) tropical rainy climates with no cool season, B) dry climates, C) middle-latitude rainy climates with mild winters, D) middle-latitude rainy climates with severe winters and E) polar climates with no warm season.

Each of these group is subdivided into climatic types based upon the seasonal distribution of rain-fall or the degree of dryness or cold.

Our interest for this study is the dry climate group and its subdivisions.

2.2 THE DRY CLIMATE

There are two main subdivisions of dry climates, the arid or desert, and the semi-arid or steppe type (Thornthwaites, 1954).

2.2.1 Definition of dry climate

"The essential feature of a dry climate is that the annual water loss through evapotranspiration at the earth's land water surface exceeds the annual water gain from precipitation" (Trewartha, 1968). Koenigsberger and Ingersoll (1974) defined a dry climate as one where heat is

a dominant problem, when, for the greater part of the year, buildings serve to keep the occupants cool rather than warm.

2.2.2 Boundaries and characters of dry climate

Dry climates cover most of the world's land area and according to Köppen occupy 26% of the continental area. Of this total, 14% is semiarid and 12% is arid. (Lockwood, 1974).

Strahler (1961) notes that deficiency of rain depends not only upon the quantity that falls but also upon the rate at which it is lost through plants. It is clear that no specific amount of rain can be accepted as the boundary of all dry climates. The rate of evaporations varies widely over the earth, depending largely upon temperature. Trewartha (1968) has mentioned that the boundary between dry and humid climates can be drawn where the average annual precipitation equals the annual evapotranspiration.

Trewartha (1937) has mentioned that generally the large daily temperature ranges with clear, cloudless skies and relatively low humidity characterize the dry climate. This permits an abundance of solar energy to reach the earth by day but likewise allows a rapid loss of earth energy at night. Large diurnal ranges in deserts are also associated with the meager vegetation cover, which permits the barren surface to become intensely heated by sun. According to a physical law, the higher the temperature of a body, the more rapid is its loss of heat by radiation and consequently the more rapid its reduction in temperature. Therefore the desert not only acquires heat quickly but also loses it very fast.

Rainfall in the dry climates is always meager. Relative humidity is low, 12 to 30% being usual for midday hours. Conversely, potential evaporation is extremely high. The absolute humidity is always low, for hot desert air usually contains a quantity of water vapour, but it may be far from saturated (Trewartha, 1968).

Winds in dry regions are inclined to be strong. Trewartha (1968) attri-

butes this to "the rapid daytime heating of the lower air over desert" which leads to strong convèctional overturning and this interchange of lower and upper air tends to accelerate horizontal surface currents during warm hours when convection is at a maximum".

Desert air is often murky with fine dust which fills the eyes, nose and throat, causing serious discomfort (Trewartha 1968).

2.2.3 Boundaries and definition of arid and semi-arid zones

Meigs (1953) has stated that "arid areas are those in which the rainfall on a given place of land is not adequate for crop production. In the semi-arid lands, rainfall is sufficient for certain types of crops and grass is an important element of the natural vegetation unless over-grazing has replaced it with brush".

Within desert 'Arid zone' there are many degrees of dryness. Meigs, (1953) has only divided this zone into two subdivisions, extremely arid and arid, see map in Figure 2.2.1.

2.2.4 The climate of hot arid zones (extreme arid)

According to Koenigsberger and Ingersoll (1974), "These climates occur in two belts at latitudes between approximately 15° and 30° north and south of the equator. An example of settlements in this zone is Aswan".

Ground conditions

The ground is very dry and barren owing to the scant vegetation, often with red or brown sand and rock. There is uncomfortable glare due to the exceptionally high amount of reflected light. Considerable wind erosion exists, due to wind-blown sand and shifting dunes (Lippsmeier 1969 and Flohn, 1969).

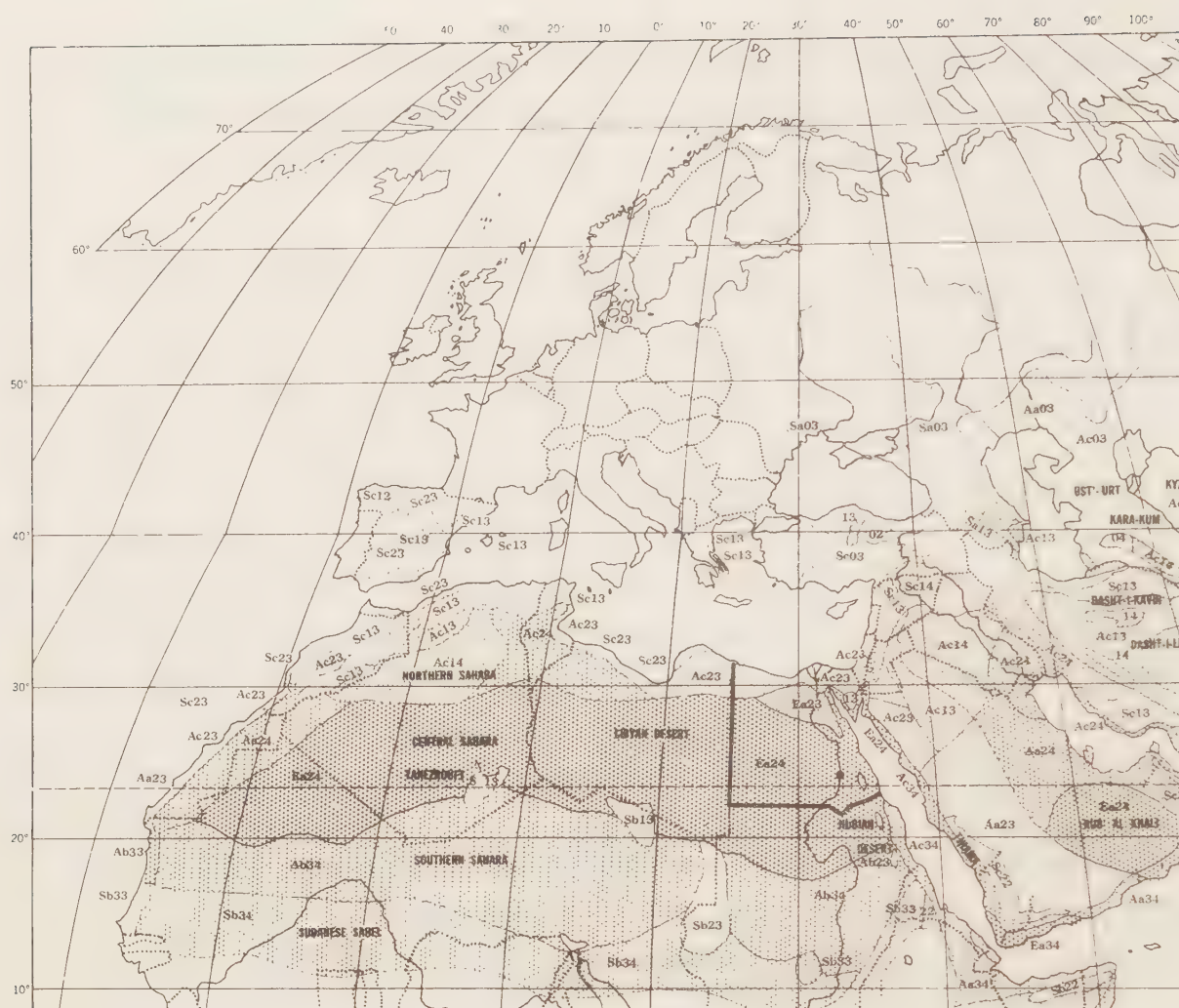


Figure 2.2.1 Distribution of arid Homoclimates in Egypt and surrounding areas (Meigs, 1953).

On the map the degree of aridity is shown (Meigs, 1953):

E = extremely arid, at least one year without rain

A = arid, deficit of precipitation in relation to evaporation

S = semi-arid, deficit of precipitation in relation to evaporation

The season of precipitation is denoted by the use of letters: "a" no distinct seasonality of precipitation, "b" summer precipitation, and "c" winter precipitation.

The mean temperature of the coldest and warmest months respectively is indicated on the map by a pair of numbers denoting the following ranges:

0 = below 0°C

1 = between 0 and 20 °C

2 = between 10 and 20 °C

3 = between 20 and 30 °C

4 = above 30 °C

Temperature

The annual range of temperatures in the arid deserts is larger than in any other type of climate within the tropics. Aswan in Egypt has mean temperatures of 16°C in January and 35°C in July. This results in an annual range of 19°C . This is due, not only to the clear skies and the bare desert, but to somewhat greater extremes of insolation as compared with most of the humid areas. (Trewartha, 1968).

It should be emphasized that it is the excessive summer heat, rather than the winter cold, which leads to the marked difference between the seasons. This is one of the major characteristics of arid climates, where the annual range may occasionally equal daily ranges. The latter, however, are usually larger, averaging 17 to 25°C . (Koenigsberger and Ingersoll, 1974).

The same conditions - dry air, cloudless skies and bare dry earth - that result in relatively large temperature differences between the extreme months are likewise conducive to wide differences within the 24 hours. "On December 25, 1878, at Bir Milrha (south of Tripoli, Libya) in the Sahara, a minimum temperature of -0.5°C and a maximum of 37°C were recorded on the same day". (Trewartha, 1968). "At El Azizia (south of Tripoli, Libya) 57.8°C has been recorded, this being the highest air temperature in the shade". (Trewartha, 1968). During the period of low sun, the days are still warm, with the daily maximum usually averaging 26°C .

Sky conditions and sunshine

Skies are usually clear in the desert so that sunshine is abundant. Over much of the Sahara in December and January cloud covers amounts to only 1/10, while from June to October it drops to about 1/30 (Lockwood, 1974).

Strong surface heating, due to the intense insolation and the nearly bare ground in conjunction with the warm masses of air of low relative humidity, will give rise to vigorous convectional currents. However, "In spite of the low humidity, strong nocturnal cooling in the desert

frequently is sufficient to produce valley fogs and dew". (Trewartha, 1937).

Koenigsberger and Ingersoll (1974) mention that the sky is usually a dark blue, with a luminance of 1700 to 2500 cd/m^2 , and darkens during dust or sandstorms to 850 cd/m^2 or even less. Towards the end of the hot period, dust suspended in the air may create a white haze with a luminance of 3500 to 10000 cd/m^2 , which produces a diffuse light and a painful glare.

Solar radiation is direct and strong during the day, but the absence of clouds permits an easy release of the heat stored during daytime in the form of long-wave radiation towards the cold night sky.

Precipitation and humidity

Desert rainfall is so meager and so erratic in its time of fall that its distribution throughout the year is of almost no consequence. Over much of the Sahara precipitation is under 127 mm. At Cairo the annual rain-fall averages 30 mm (Trewartha, 1937). Lippsmeier (1969) says in general in hot, arid zones that the humidity (vapour pressure) is low, 7-15 mb, and the relative humidity 10-55%.

Over large parts of the desert, widespread rains are almost unknown. Trewartha (1968) noted that as low as 2% relative humidity with a temperature over 38 °C has been recorded in the Egyptian Sahara. It was the extraordinarily dry air which allowed the Egyptians to mummify their dead.

Wind

The winds are usually local. The heating of air over hot ground causes a temperature inversion, and with the lower warm air mass breaking through the higher cooler air, local whirlwinds are often created. In some seasons winds carrying dust and sand often develop into dust-storms. (Koenigsberger and Ingersoll, 1974).

2.3 CLIMATE OF EGYPT

Egypt forms a part of the great Sahara-Arabian desert which stretches from the Atlantic to the Indian oceans between approximately 15° and 30° north latitude with an arid climate over a large part of the land during the whole year. (Unesco, 1963).

However, in Egypt there are three exceptions to pure desert conditions:

a) along the river banks, b) along the Mediterranean littoral where there is winter rainfall, and c) in the great oases. (Simaika, 1953).

Sutton (1950) has mentioned that "In general, the weather in Egypt is very stable for a great part of the year".

The annual climate of Egypt can be divided into two main seasons:

a) a long, hot and dry summer period. b) a short, mild and dry winter, rainy along the coast, and two transitional periods.

2.3.1 Temperature

During the period from March to the end of May, which is a transitional period to summer conditions, the air is dry and the wind southerly.

This period ends with the Khamasin weather, which goes on for about one week. 'Khamasin' is the Arabic word for fifty and is so called because it comes about fifty days after the Coptic Easter. The atmosphere during this period is hazy with sandstorms and with temperatures of 45°C at Cairo and 50°C at Aswan. (Sutton, 1965).

"On the passage of such a depression the south wind drops and is replaced, often with an impressive abruptness, by a comparatively cool wind from the northwest, marking the arrival of the cold front. Since the air of the cold sector has crossed the Mediterranean and displaced the desert air, a large and rapid increase in humidity invariably takes place. Changes of this kind are especially noticeable along the coast to the west of Alexandria, where maritime and desert conditions are strongly contrasted and in these circumstances the humidity may rise from less than 5% to over 80% within a few minutes. The cold front is

often marked by a line-duststorm in which visibility is reduced to only a few yards. The dust may rise to a height of several thousand feet, and be transported and deposited hundreds of miles away. Thunderstorms also sometimes occur, but usually the air is then too dry for much rain to reach the ground". (Sutton, 1950).

"The long, hot, dry period of summer starts early in June and continues until October. The wind is almost steady from the north and there is very little cloud with high insolation. The large quantity of solar radiation received goes into heating the ground. The surface temperature of the sand often exceeds 65 °C near Cairo". (Kendrew, 1942).

From October to early November, which is a transition period to winter conditions, the temperature is usually stable, but a heat wave is occasionally experienced in October and the temperature is still high.

From November to February, which is the winter period, the temperature during the day rises on the average to 19 °C along the Mediterranean coast and as far inland as Cairo. In upper Egypt (Aswan), the days become appreciably warmer as one goes south. The maximum temperature is in average 23 °C at Aswan.

In mid-winter the temperature generally falls at night to 10 °C on the coast and 7 °C in Cairo. (Sutton, 1950).

At Aswan, with its typical continental desert location, the soil is dry and the average annual rain fall is below 2 mm, leading to extremely high temperatures. (Climate normal, 1938).

Temperature data are given in Tables 2.3.1 - 2.3.3 and in Figures 2.3.2 - 2.3.5.

"The highest values of the diurnal temperature range are experienced in the desert, where the soil is generally dry and the atmosphere contains little vapour. The low water vapour content of the air allows relatively large long-wave radiation from the surface, leading to low temperature at night". (Lockwood, 1974).

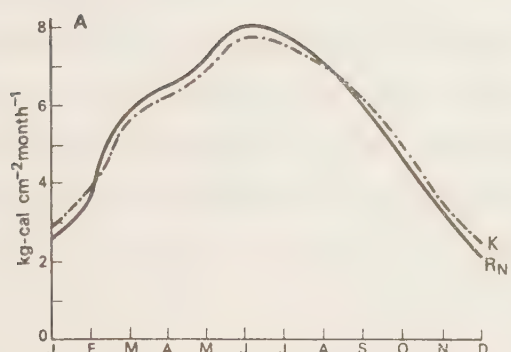


Figure 2.3.1 Average heat balance at Aswan. K=sensible heat transfer to the atmosphere from the ground. R=net radiation. (Lockwood, 1974).

2.3.2 Solar radiation

The intensity of the insolation is a function of the solar angle altitude and the transparency of the atmosphere. It is highest when the sun is nearest the zenith. The sun's noon altitude in Egypt varies from that in Alexandria (latitude N $31^{\circ}12'$) where the summer solstice is $82^{\circ}15'$ and the winter solstice $32^{\circ}21'$ to Aswan (latitude N $24^{\circ}2'$), where the summer solstice is $89^{\circ}25'$ and the winter solstice is $42^{\circ}31'$ (Strahler, 1961).

"In Egypt, particularly in the Nile Valley, sand and dust particles are blown up from the desert surfaces and remain in suspension in the lower layers of the atmosphere, making the sky very bright. In winter at night, the atmosphere is more stable and therefore clear. The stars shine very brightly and the air is highly transparent. During the Khamsin the dust may rise very high and the sun is obscured, while the land is buried under a stifling cloud of dust". (Sutton, 1950).

Solar radiation data for Cairo are given in Table 2.3.4.

2.3.3 Sunshine and cloudiness

Bright sunshine is a characteristic of the Egyptian climate. Cloudless skies are the rule during the greater part of the year (Sutton, 1950). Early morning fog arises along the Mediterranean in winter and thick fog or low clouds are formed in the Delta and Nile Valley in summer and autumn. The fog dissipates soon after sunrise and reduces only slightly the total duration of bright sunshine. The fog helps, however, to shield the sun in the early mornings of summer, thereby reducing the daily heat-gain. (Sutton, 1950).

Data about clouds can be found in Table 2.3.2 and 2.3.3 for Cairo and Aswan.

2.3.4 Rainfall

The distribution of the mean annual amount of rainfall over Egypt shows a maximum on the Mediterranean coast with a rapid decrease inland. At Aswan it is practically rainless (Lockwood, 1974). In general rainfall in Egypt is small and subject to relative variation from season to season. (Climate Normals, 1938).

Rainfall occurs entirely in the period from October to May, December and January being the rainiest months. The rainiest part of the country is the coastal strip extending from Alexandria to the northern tip of the Nile delta, where the precipitation averages 200 mm a year, half of which falls in December and January. (Sutton, 1950).

Rainfall decreases rapidly with increasing distance from the coast, averaging 70 mm in the middle of the Delta.

Thunderstorms are most frequent in November and early December. In the desert, especially east of the Nile, grass for the livestock of the Bedouins and the supply of well water are entirely dependent on the sparse and irregular rains. (Sutton, 1950).

The annual rainfall is shown in Figure 2.3.6.

2.3.5 Humidity

The mean relative humidity in summer averages 75% at Alexandria, 60% at Cairo and 30% at Aswan. The average values in winter are 65%, 70% and 40% respectively. On the coast the diurnal variation of humidity is about 16%, but inland the variation during the twenty-four hours is very great, amounting to nearly 50% in the Delta and Cairo. In the cultivated areas the relative humidity falls from 90% in the early morning to 45% in the afternoon in January, and from 76% to 27% in July. The wet-bulb temperature at Alexandria in July and August averages 25.5 °C at its highest in the early afternoon and varies little throughout the day and night. On damp days in late summer, the wet-bulb temperature in Cairo may reach 26 °C. (Sutton, 1950).

The relative humidity for days in January and July is given in Figure 2.3.7 and vapour pressure data in Figures 2.3.8 - 2.3.9.

2.3.6 Wind

During the winter, the Mediterranean weather front is formed on the border between cold European air and the milder air prevailing over the sea and desert (Pettersson, 1958). The storms which develop along this front travel from west to east along the Mediterranean and bring a complete change of weather to the northern coastal region of Egypt. The effect of these storms decreases with increasing distance from the coast. During the summer season the front is absent and the prevailing wind is northerly. (Sutton, 1950).

Wind data are given in Figures 2.3.10 - 2.3.12.

2.3.7 Ground temperatures

Table 2.3.5 shows the temperatures at different levels below the ground surface for a place in the desert near Aswan.

2.3.8 Water temperatures in the river Nile

In Table 2.3.6 the water temperatures for the river Nile are shown at the delta and at Aswan.

Table 2.3.1 Climatic data (Afro Asian, housing organization, Cairo 1963. After The Meteorological Department, 1950).

	ALEXANDRIA				CAIRO				ASWAN						
	Mar.	June	Sep.	Dec.	Aver- age	Mar.	June	Sep.	Dec.	Aver- age	Mar.	June	Sep.	Dec.	Aver- age
Pressure (m.b.)	16.0	12.3	13.5	18.2	1014.7	15.3	11.0	12.4	18.2	1013.9	13.2	7.2	8.4	16.7	1011.4*
Max. °C	21.2	28.2	29.9	20.6	25.0	24.5	41.2	32.6	21.4	28.7	30.4	47.2	39.4	25.3	34.2
Min. °C	12.8	20.8	22.6	12.6	17.3	10.6	24.4	19.9	9.6	15.2	14.5	21.6	24.0	11.8	19.2
Mean °C	15.8	23.6	25.3	15.7	20.2	16.3	32.8	25.3	14.0	20.8	21.3	34.4	30.9	17.4	25.8
R.humidity %	68	74	69	70	1	65	55	69	76	66	32	25	33	45	34
Rain-fall mm	10	-	1	56	184	4	-	-	5	26	-	-	-	-	3**
Wind speed miles/h	16.3	15.3	13.1	12.8	14.4	8.4	7.9	5.8	6.7	7.2	5.5	4.8	3.1	3.9	4.3
Percent of prevailing wind	W	N	E	S	Calm	W	N	E	S	Calm	W	N	E	S***	Calm
	N.W	N.E	S.E	S.W		N.W	N.E	S.E	S.W		N.W	N.E	S.E	S.W	
	33.4	39.9	10.5	8.7	7.5	25.7	38.0	3.9	15.2	17.2	8.7	47.6	1.2	1.3	41.2

*) The average increased according to higher pressure in January (=1019 millibar)
**) The average of rain-fall is the amount of millimetres falling each month of the year.
***) W=West, N=North, S=South, E=East.

Table 2.3.2 Meteorological data for Cairo 29°52'N, 31°20'E (Column 1-3, Meteorological office, 1972 and column 4-6 Climato-
logical normals, Ministry of public works, Physical department, Cairo 1938).

Period 1901-1945	1) Temperature °C		2) R.Humidity		3) Precipitation		4) Cloud		5) pressure		6) Vapour pressure	
	Average of		Absolute		Percent at		Maximum		Amount		Mean	
	Average daily	highest each month	lowest each month	Max.	Min.	0800	1400	Average monthly fall	fall in 24 h	Mean of day	Mean of day	Mean of day
	Max.	Min.						(mm)	(mm)	0-10	m.b.	m.b.
January	18.2	8.3	23.3	4.4	31.1	1.6	69	0.5	0.3	4.1	1016.2	10.0
February	20.5	8.8	27.2	5.0	33.3	1.6	64	0.5	2.3	3.5	14.3	9.7
March	23.8	11.1	32.7	6.6	38.3	3.3	63	0.5	2.5	2.6	12.8	11.3
April	28.3	13.8	37.7	9.4	45.0	5.5	55	0.3	3.8	2.1	11.4	12.8
May	32.7	17.2	40.0	13.3	46.6	9.4	50	0.3	2.8	1.8	10.0	14.5
June	35.0	20.0	41.1	16.6	47.2	12.7	55	0.3	0.3	0.7	8.6	17.8
July	35.5	21.1	39.4	20.0	42.7	16.1	65	0.0	0.0	1.1	5.9	20.8
August	35.0	21.6	38.3	20.0	42.7	17.2	69	0.0	0.0	1.2	6.7	22.1
September	32.2	20.0	36.1	17.7	42.2	14.4	68	0.3	0.3	1.3	9.9	21.1
October	30.0	18.3	35.5	15.0	42.7	10.5	67	0.3	2.3	1.8	13.0	18.4
November	25.5	14.4	31.6	10.0	37.7	5.5	68	0.3	1.3	2.8	14.3	15.1
December	20.0	10.0	26.1	6.1	30.5	1.1	70	0.5	2.8	3.7	15.5	11.6

Table 2.3.3 Meteorological data for Aswan 24°02'N, 32°53'E, (Column 1-3 Meteorological office World, London 1972 and column 4-6 Climatological Normals Ministry of public works, Physical department, Cairo 1938).

Period	1) Temperature °C				2) R.Humidity		3) Percipitation		4) Cloud	5) Pressure	6) Vapour pressure		
1901-1945	Average daily		Average of		Absolute		Percent at		Maximum		Mean		
			highest	lowest					fall in		of day		
	Max.	Min.	each month	each month	Max.	Min.	0800	1400	(mm)	(mm)	Amount Mean of day	Mean of day	
January	23.3	10.0	31.6	5.5	37.7	3.3	52	29	3	3	1.3	1005.6	7.7
February	25.5	11.1	34.4	6.1	38.8	1.6	46	22	3	3	1.2	4.4	7.6
March	30.5	14.4	40.0	8.8	43.3	6.1	36	17	3	3	1.0	1.8	8.5
April	35.5	18.8	43.8	13.3	46.1	9.4	29	15	3	3	1.0	999.5	10.0
May	39.4	23.3	46.1	17.2	47.7	11.1	29	15	3	5	0.9	98.0	13.5
June	41.6	25.5	47.2	21.6	50.5	20.0	26	16	3	3	0.2	96.2	14.8
July	41.1	26.1	46.1	23.3	51.1	21.1	31	16	0	0	0.2	94.8	15.2
August	41.1	26.1	45.5	23.3	48.8	19.4	34	18	0	0	0.2	95.1	15.0
September	39.4	23.8	44.4	20.5	47.2	17.2	37	19	0	0	0.2	97.2	14.0
October	36.6	21.6	42.7	17.2	44.4	13.8	40	21	3	5	0.2	1000.0	13.1
November	30.5	16.6	38.3	11.6	41.6	6.1	46	26	3	3	0.7	2.6	11.2
December	25.0	11.6	32.7	6.1	37.2	4.4	50	31	3	3	1.0	5.0	8.7

Table 2.3.4 Solar radiation on horizontal surfaces in Cairo (Cal Cm⁻²Day⁻¹).
(Monthly Climatic data for the world, 1965).

Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1964	282	385	472	560	656	672	680	612	534	423	303	248	486
1965	300	439	535	572	707	717	698	640	552	408	339	309	518
1966	308	396	497	594	649	692	687	630	522	422	319	269	499
1967	312	356	500	599	624	688	681	622	529	393	298	256	488
1968	287	361	448	527	598	636	633	571	444	370	296	245	451

Table 2.3.5 Ground temperatures for Aswan, (Climatological Normals, Ministry of public works Physical department, Cairo 1938).

Depth of temperature point (mm)	From Daily Reading at 1400 (2 pm)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec. Mean
250.....	13.8	14.4	18.2	22.8	25.6	29.3	30.9	31.4	29.1	27.2	20.9	15.4 23.2
550.....	16.1	16.7	18.9	22.3	25.6	28.6	30.5	30.8	29.6	28.2	24.2	19.1 24.2
850.....	17.9	17.7	19.0	21.5	24.4	27.3	29.3	29.6	29.2	28.3	25.2	21.2 24.2
1150.....	18.4	18.1	19.0	21.0	23.8	26.4	28.6	28.9	28.9	28.0	25.6	21.8 24.0

Table 2.3.6 Water temperatures in the river Nile at Delta and Aswan, (Climatological Normals Ministry of public works, Physical department, Cairo 1938).

	From Daily Reading at Delta 0800 (8 am) at Aswan 0700 (7 am)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec. Year
Normal	14.7	14.8	17.5	20.3	23.4	25.6	27.1	27.3	25.7	23.6	21.1	16.6 21.5
Highest Reading	17.2	17.5	20.7	25.0	26.8	27.8	29.5	29.9	28.2	25.9	25.2	19.8 ----
Lowest Reading	12.0	12.3	13.5	17.0	19.4	23.6	25.0	25.0	23.5	21.0	17.3	13.5 ----
Normal	16.7	16.6	18.3	21.1	24.5	26.9	27.3	27.5	26.2	24.3	21.8	19.1 22.5
Highest Reading	20.0	19.0	21.0	25.0	28.0	28.9	30.0	29.9	28.0	27.0	26.0	22.0 ----
Lowest Reading	14.0	14.0	16.0	18.0	21.0	25.0	26.0	25.0	22.0	19.0	18.0	16.0 ----

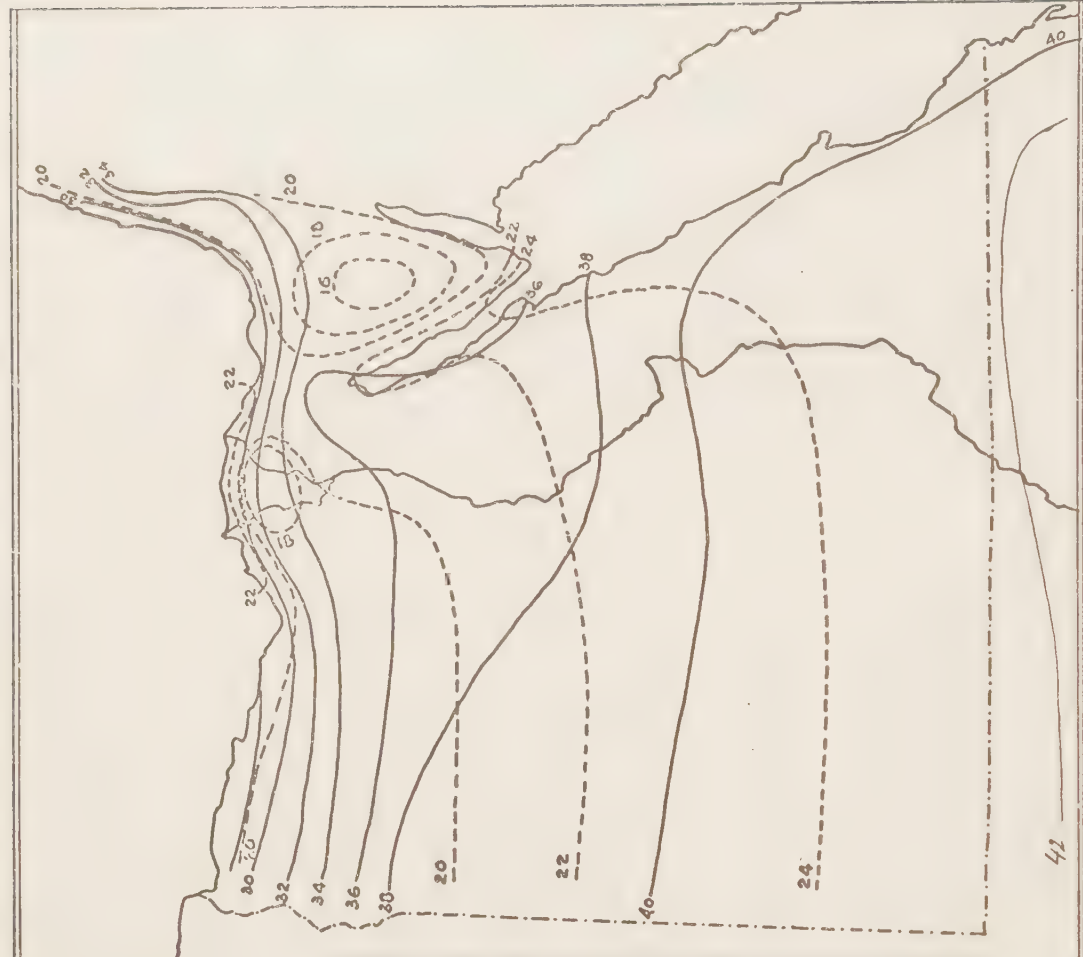


Figure 2.3.3 Temperature, July Mean Daily Max. ———
Mean Daily Min.
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931).

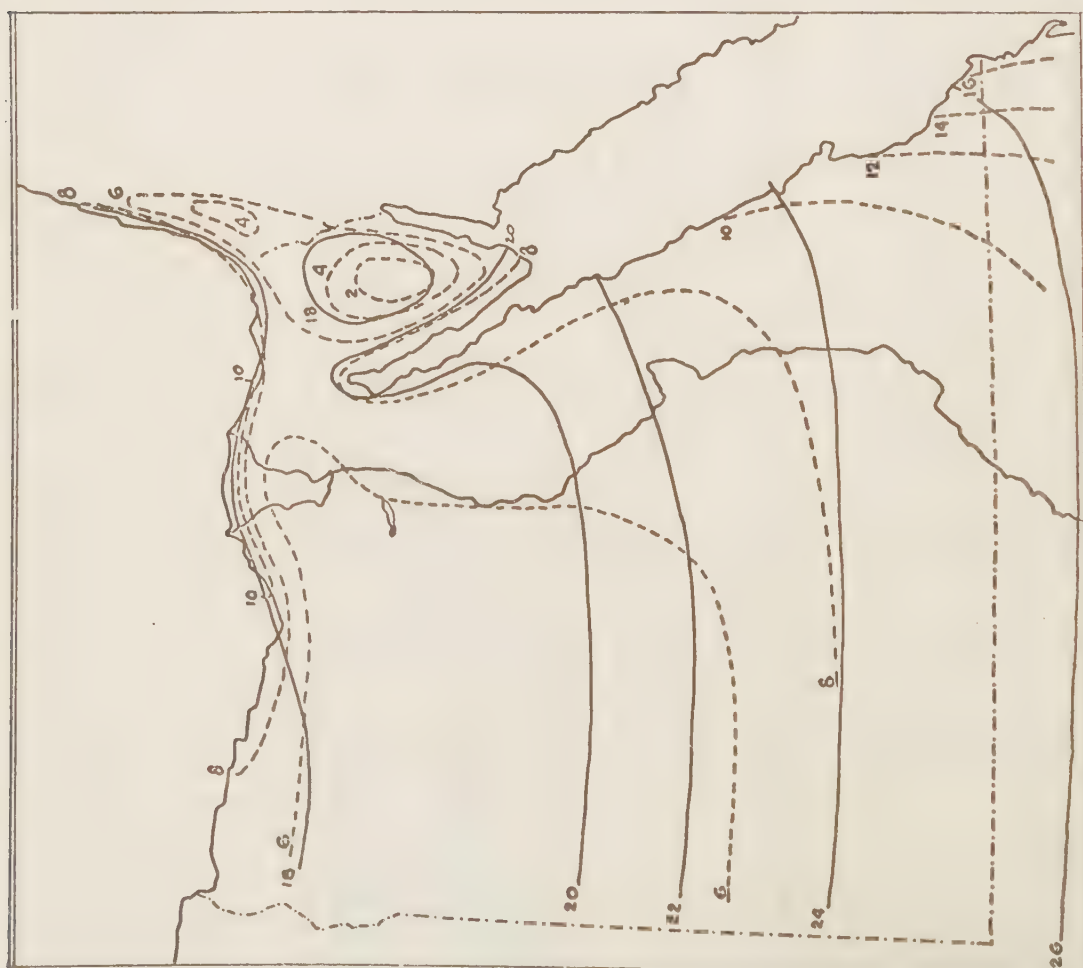


Figure 2.3.2 Temperature, January Mean Daily Max. ———
Mean Daily Min.
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931).

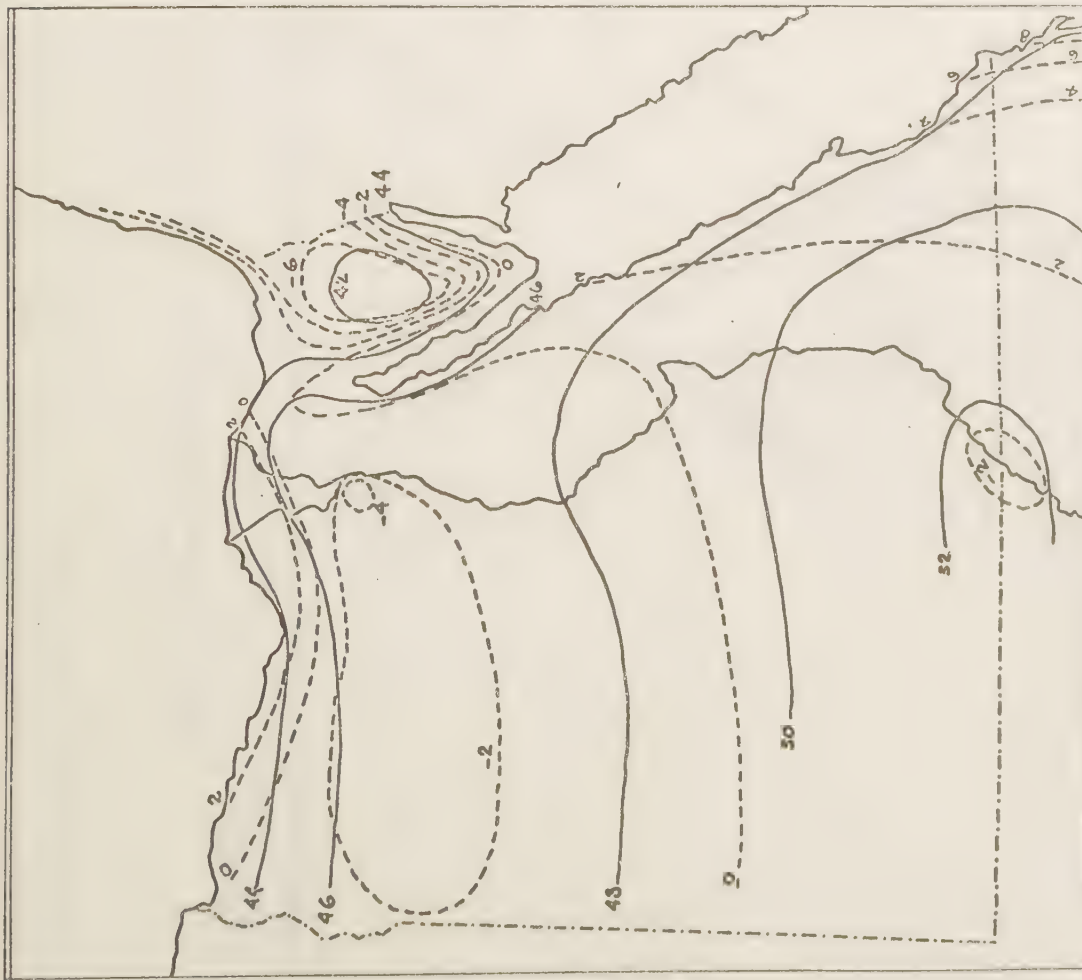


Figure 2.3.4 Temperature, Absolute Max.—— Min.
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931)

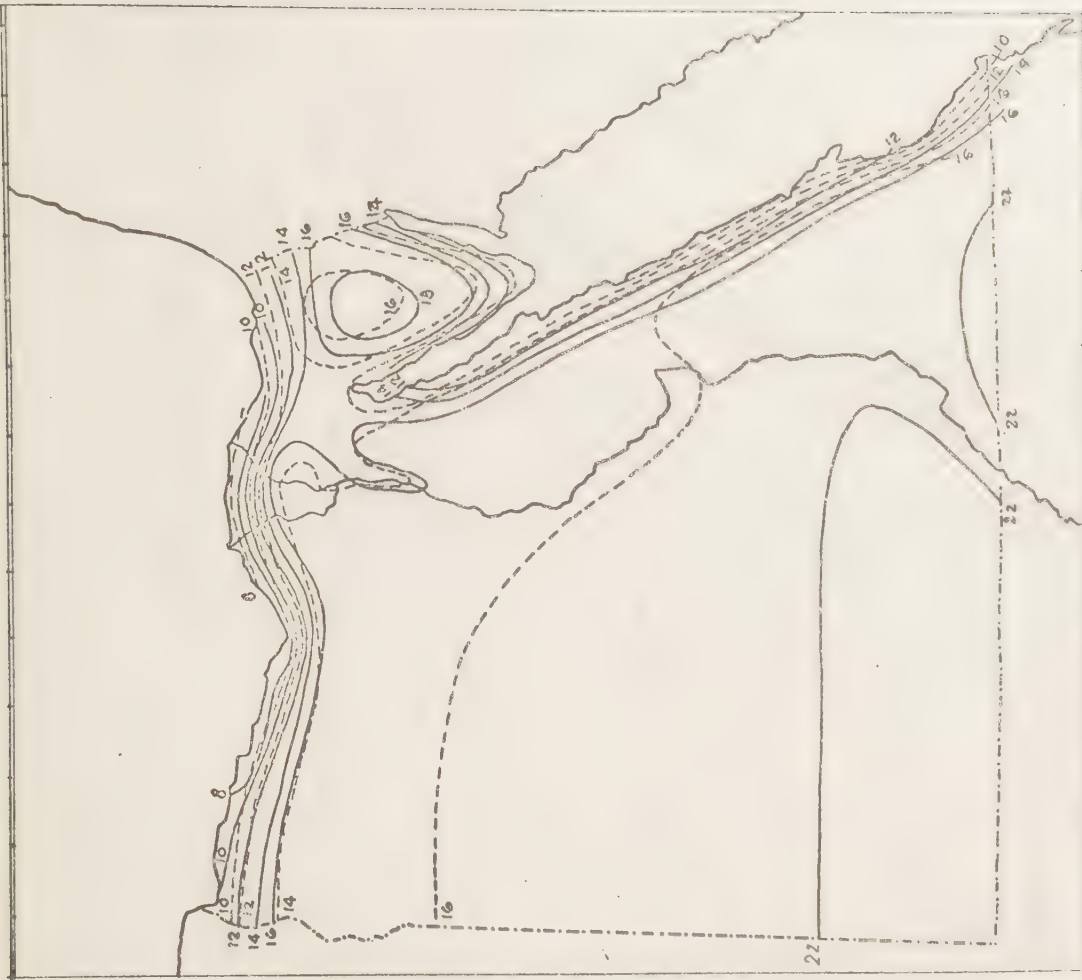


Figure 2.3.5 Temperature, Diurnal variation January July
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931).

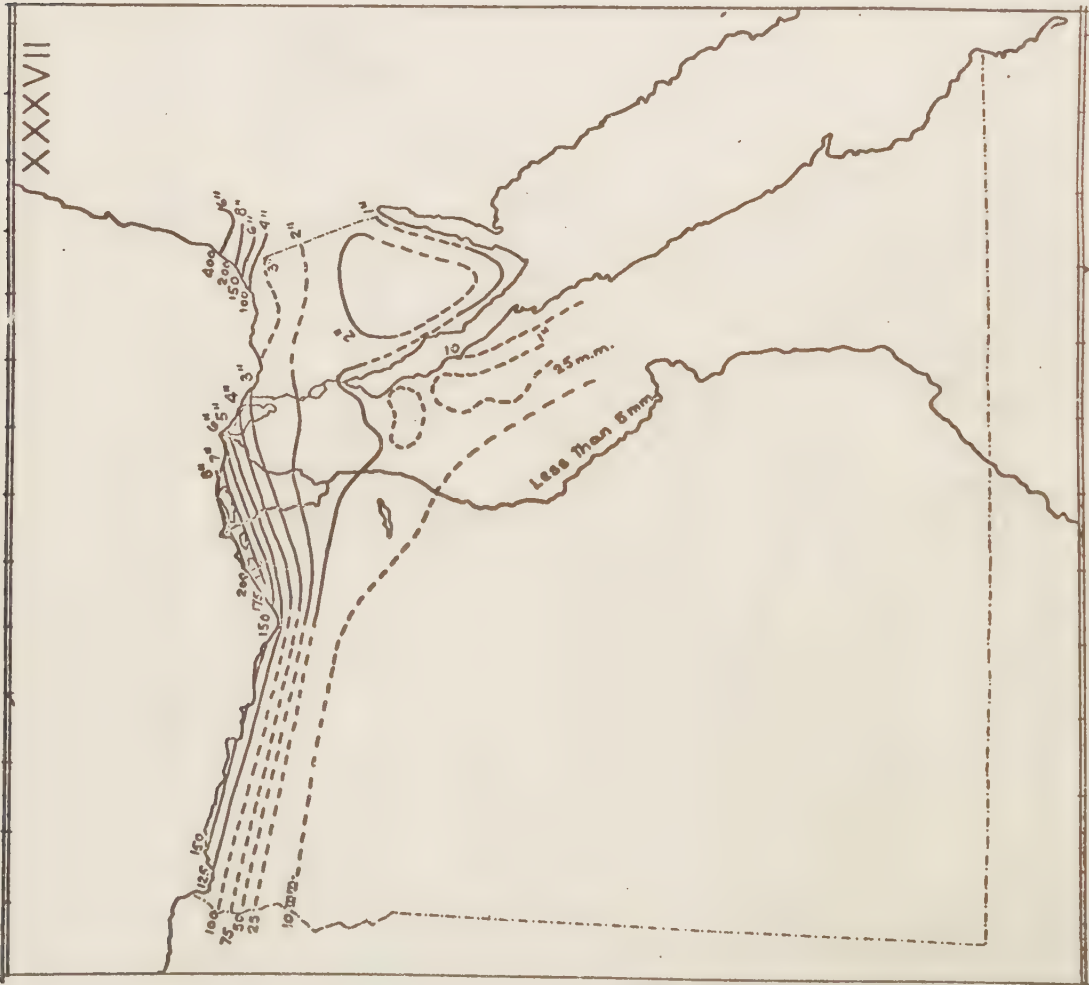


Figure 2.3.6 Annual rainfall (mm)
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931)



Figure 2.3.7 Relative humidity (%) January July
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931)

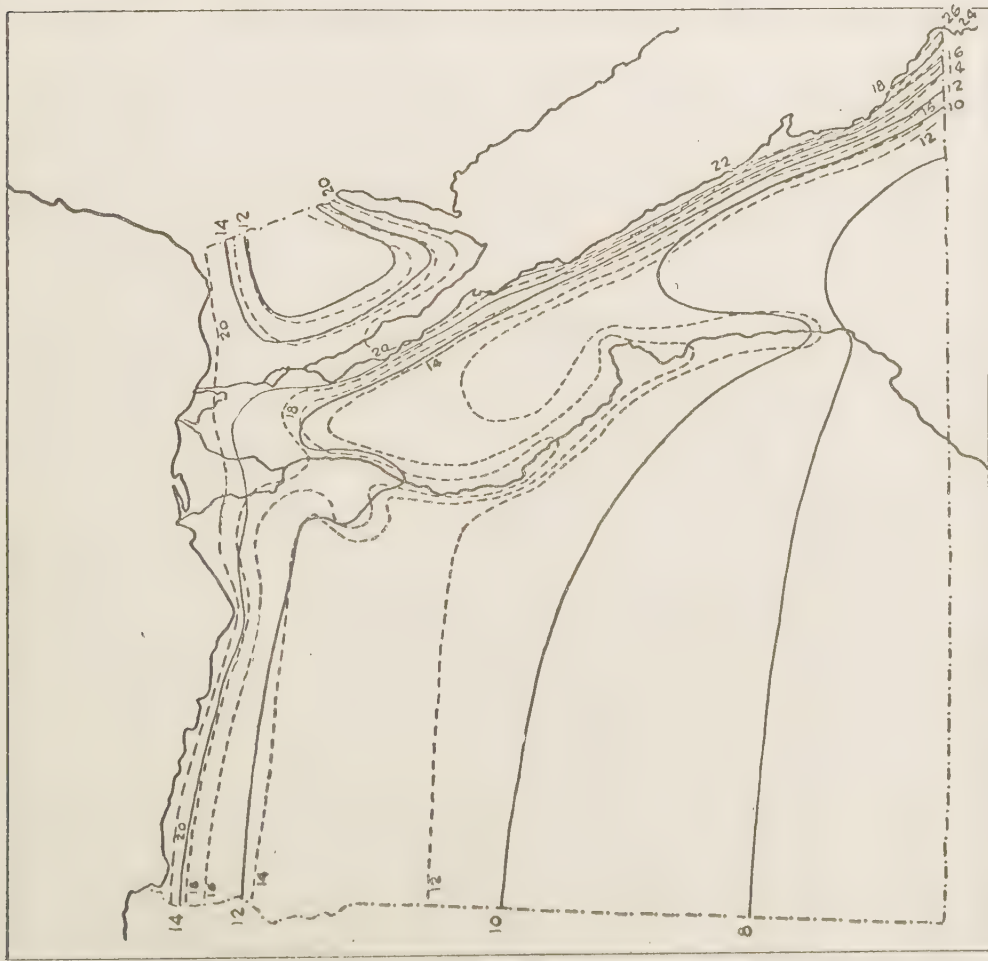


Figure 2.3.8 Vapour Pressure Mean of day (8, 14, 20h) millibar
 October
 April _____

(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931).

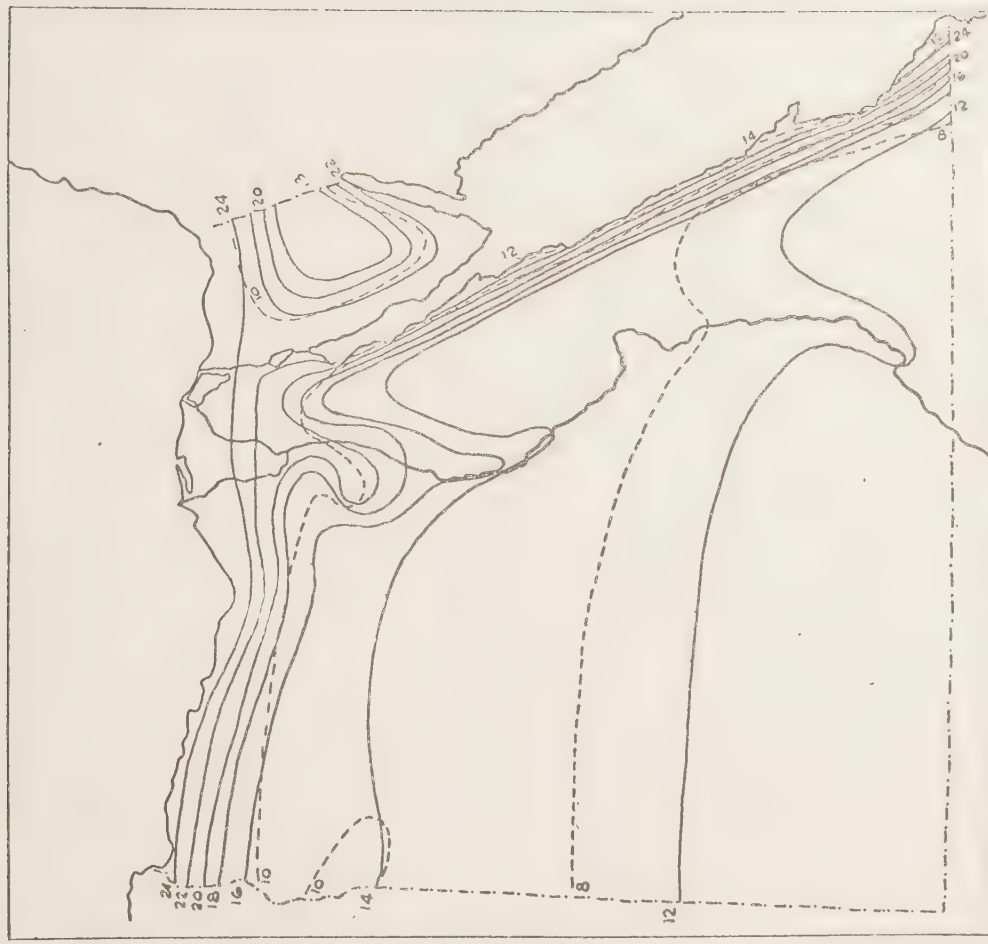


Figure 2.3.9 Vapour Pressure Mean of day (8, 14, 20) millibar
 January
 July _____

(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931).

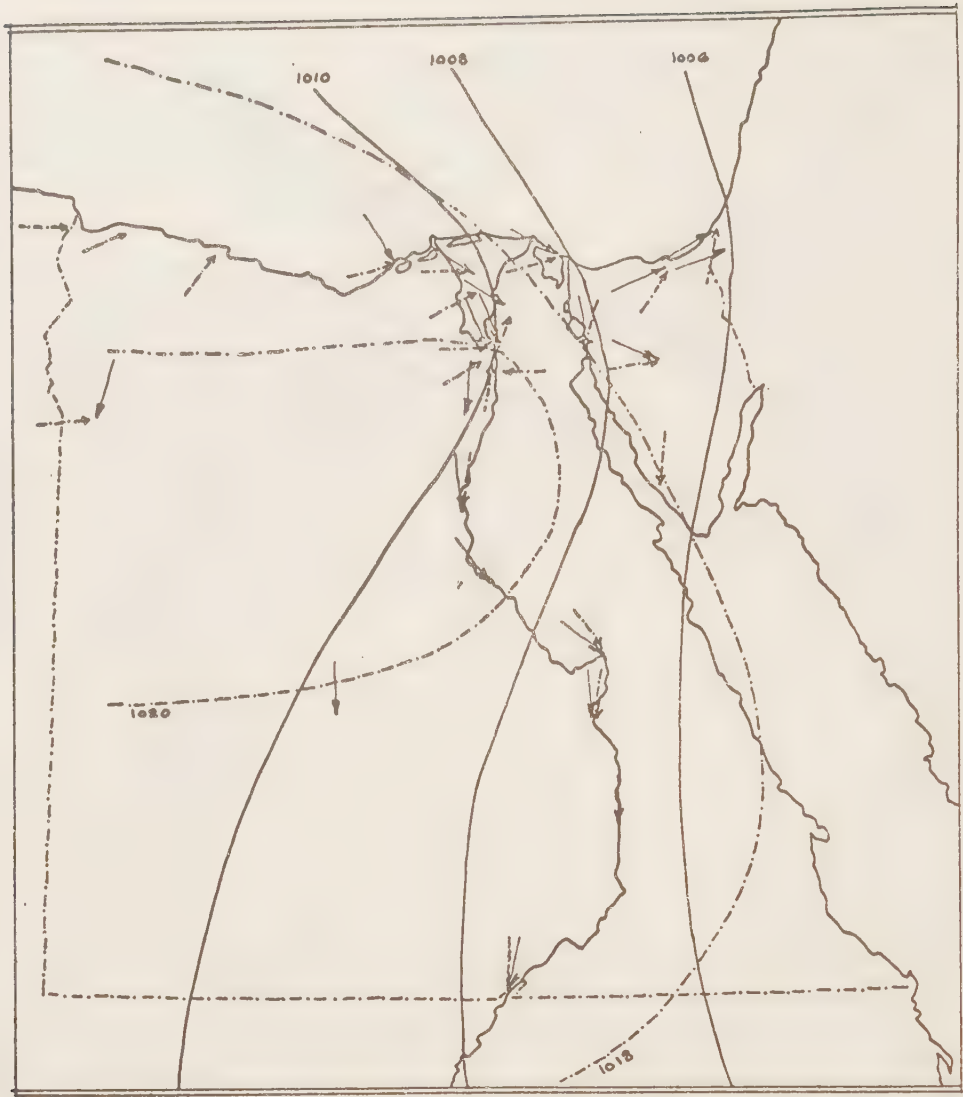


Figure 2.3.10 Prevailing wind and air pressure (mb).
January - - - -
July ———
(Egypt Ministry of public works, Meteorological
Atlas of Egypt, 1931).

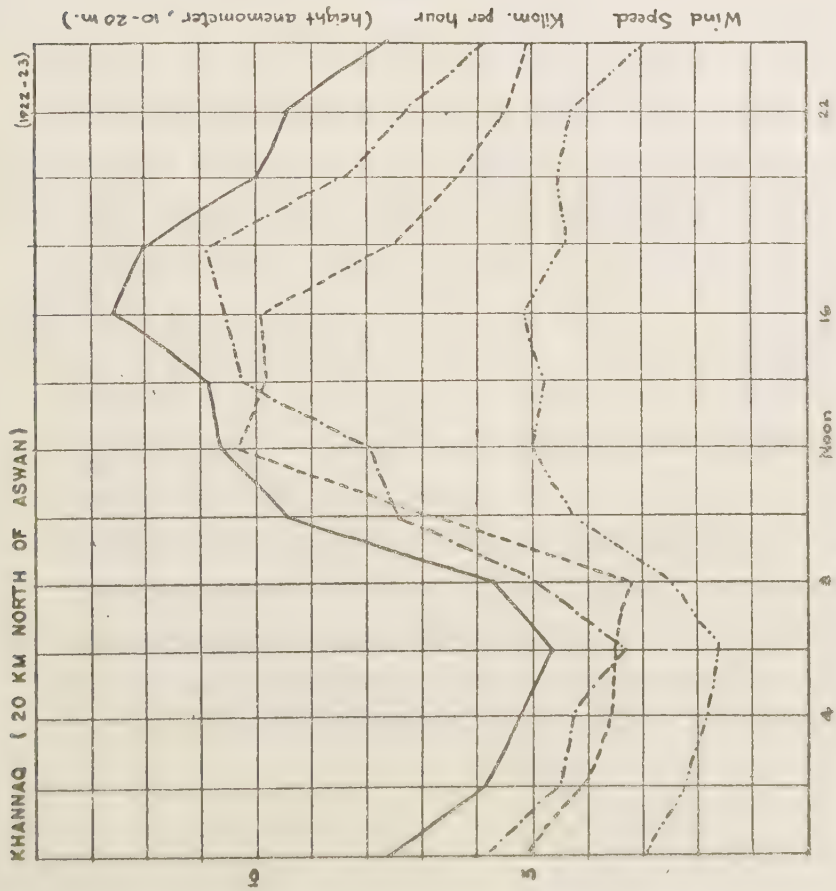


Figure 2.3.11 Wind velocity, Diurnal variation at Aswan
(from 1922-23)
Dec.-Feb.
Mar.-May
June-Aug.
Sept.-Oct.
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931)

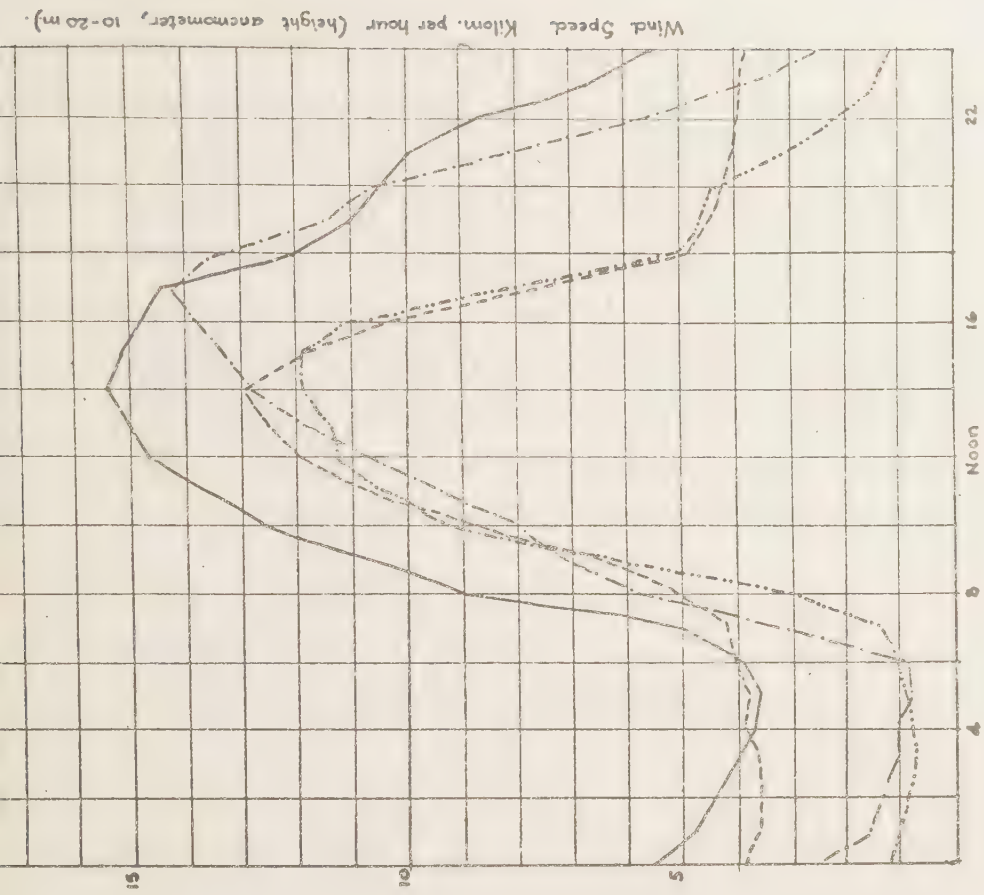


Figure 2.3.12 Wind velocity, Diurnal variation at Cairo
(from 1901-03)
Dec.-Feb.
Mar.-May
June-Aug.
Sept.-Oct.
(Egypt Ministry of public works, Meteorological Atlas of Egypt, 1931).

3 MAN'S NEED OF SUITABLE ENVIRONMENT

A fundamental objective of architecture is to create spaces for living conditions. In these spaces man should be able to maintain his physical well-being at rest or at work. His body produces heat by metabolic processes and, being a warm-blooded creature, he is provided with a temperature-regulating system which maintains a thermal balance.

The building envelope is Man's barrier against external atmospheric conditions and their fluctuations. In this sense building and clothing complement each other in providing a protective layer between Man and the surrounding atmosphere.

Egyptian civilization flourished mainly in southern (upper) Egypt, and adaptation to climate was accomplished by proper architectural design and by wearing a minimum of clothing in warm weather, which permitted body perspiration to evaporate freely in the dry air (Wulsin, 1949). Wilson (1951) has mentioned that ancient Egyptians hated the cold and greeted the warmth of the rising sun, but they avoided the blistering desert sun and welcomed the prevailing north breeze, which was worshipped as a minor deity.

Physiologically uncomfortable conditions in arid climates are mainly caused by extreme heat and dryness, both affecting the thermal balance of the body. This chapter will describe the heat exchange between the body and the ambience and the comfort range in a hot, arid zone will be discussed.

3.1 HEAT EXCHANGE PROCESSES OF THE BODY

Man's system of temperature regulation keeps his internal organs (core) at near constant temperature, close to 37°C . In order to maintain a constant internal body temperature, the organism must balance its rate of heat dissipation against its heat gain from metabolism plus any heat gained from the environment by radiation, convection and conduction.

Heat exchange between the body and the environment takes place through radiation, convection, conduction and heat lost from the body by evaporation of sweat and through respiratory heat exchange. Figure 3.1.1 shows how heat is exchanged between Man and his environment.

Leithead and Lind (1964) have stated that heat exchanges between the body and its environment can be simply represented by the heat-balance equation:

$$M \pm C \pm R - E = \pm S$$

where

- M is the heat of metabolism
- C is the body's heat gain or loss by convection
- R is the body's heat gain or loss by radiation
- E is the amount of heat lost from the body by evaporation of sweat
- S is the amount of heat gained or lost by the tissues of the body; if the body maintains thermal equilibrium, then $S=0$.

Radiation, convection and evaporation are functions of external environmental factors such as temperature, air velocity and vapour pressure of the air, mean radiant temperature of the surroundings, vapour pressure and temperature of the skin. Clothing creates a secondary environment which depends on the properties of the clothing and air flow beneath the clothing (Givoni, 1976).

The balance is maintained to some extent by control of heat production but mainly it is attained by regulation of the heat losses. Part of this control is effected by allowing peripheral areas such as the limbs to cool or warm. The changes in surface temperature cannot be attained without marked changes in temperature in the deeper tissues of the limbs. When the environment is warm and blood vessels are dilated, the hands and feet are as warm as, or warmer than, the environment. Heat losses are attainable only if the environment is capable of removing the heat generated by the body without necessitating a rise in body temperature (Bazett, 1949).

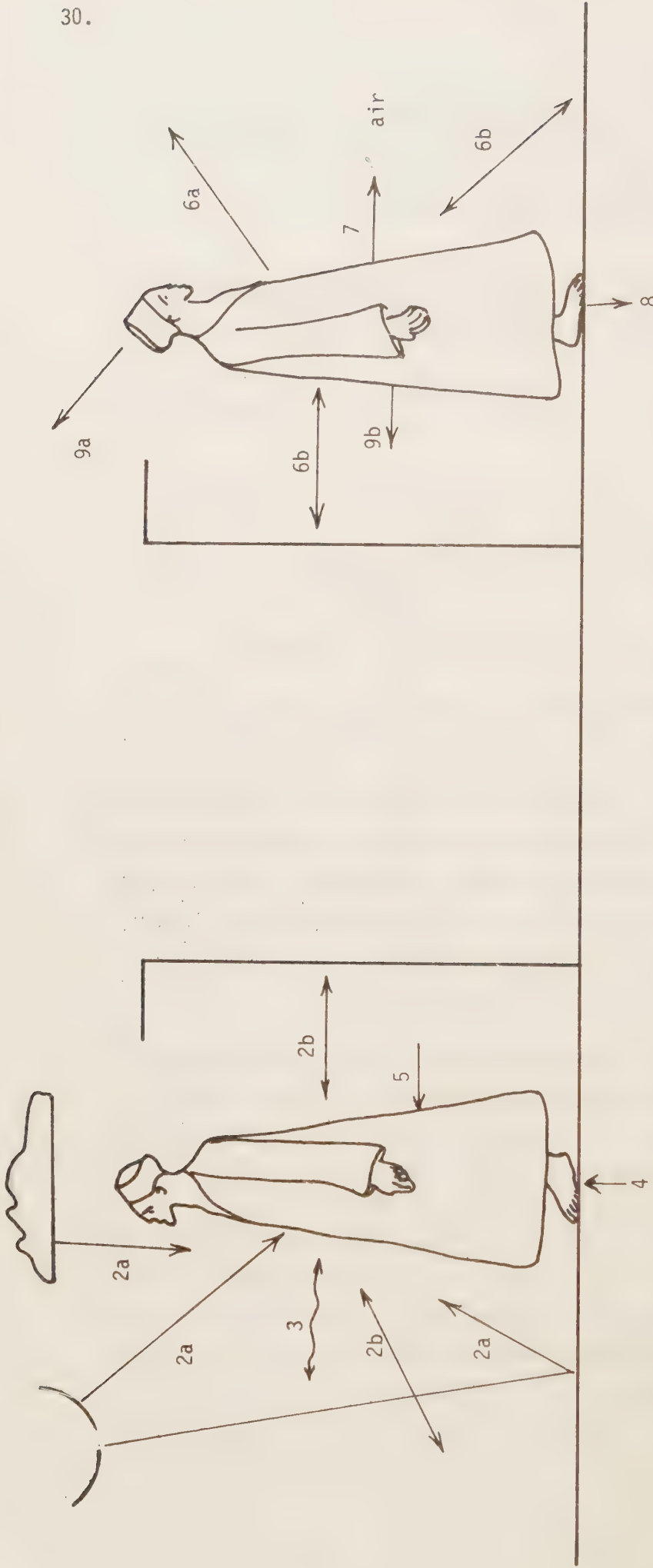


Figure 3.1.1 Heat exchange between man and surrounding. (Olgyay, 1963 and Mather, 1974).

Heat gains from environment

1. metabolism (basal and muscular)

2. absorption of radiation

- a. from sun, sky and surroundings (short-wave)
- b. from warm surfaces (long-wave)

3. convection from air (above skin temperature)

4. heat conduction (by contact with hotter objects)

5. condensation of air moisture

Heat losses to environment

6. radiation (long-wave)

- a. to the sky
- b. to colder surfaces

7. convection to air (below skin temperature)

8. heat conduction (by contact with colder objects)

9. evaporation

- a. by respiration
- b. from skin

3.2 RADIATION

In summer time life in Egypt adjusts to the heat and glare of the day. Work in the fields takes place in the early morning and in the late afternoon. During the daytime, between 1300 h and 1600 h (1 to 4 p m), people usually sleep or rest in the shade. Metabolic heat production is mainly proportional to the extent of physical activity; the lowest level is reached when the body is asleep or at rest.

In open areas man will be subjected to the heat load from both direct sun and reflected radiation. Adolph (1947) pointed out that direct solar radiation may add 170 W to a clothed person. This is sufficient to make a person feel comfortable in winter. Thanks to this, a window opening toward the south can permit solar rays to penetrate in winter and give comfort to people.

When the body is exposed to direct sunlight in summer, the skin is generally the coolest object in the environment and sun, sky and surroundings all transfer heat to the body. The proportion of solar radiation which is absorbed by the clothing surface depends on the material and colour of the clothing and also on wind speed. Forbes (1949) asked, "Do the desert Arabs with their voluminous and very loose white clothing succeed in reflecting the radiation to a large extent while impeding evaporation only to a small extent? If they do, it means a great saving in sweating and therefore in their water requirements."

3.3 CONDUCTION

Heat is conducted from the core of the human body to the skin surface and from the skin into any cooler objects with which the body may be in contact. Bazett (1947) has said: "The fact that the surfaces of the hands and feet are utilized for control is demonstrable. The feet contribute 10 per cent to the total body surface. Under hot conditions the heat lost from these areas remains continually some 13 per cent of the total basal heat production.

Fanger (1970) mentions that on a floor where people go barefooted, the flooring material is of importance for comfort, and Hardy (1949) has noted that the nature of the contact of the skin with different objects is quite important when considering the quantity of heat which is conducted out of the body. This can be noted by anyone who touches a cold smooth surface and compares the sensation with a contact with a rough surface at the same temperature.

In old traditional buildings the floor is paved with cement tiles or marble which reach up the walls about one meter. During the winter the floor is covered by woolen carpets.

3.4 CONVECTION

The exchange of heat between the body and the surrounding air is dependent mainly upon two factors: first, on the difference in temperature between the body and the air and second, on the air movement. When the air temperature is above skin temperature, heat is received by convection. Adolph (1947) has mentioned that "upon exposure to strong air currents or winds which occur either naturally or when riding in open conveyances, strong convection assures good evaporation, but it also transfers more heat from the hot air to the body. The cool air shell which surrounds the body in a quiet environment is now blown away, and thus a greater gradient exists between air and skin. Thus shelter from high winds is advisable, even though the winds may feel comfortable at the time due to the greater rate of evaporation. One pays with body water for being cooled temporarily (while exposed to wind velocity) more than need be."

3.5 EVAPORATION

When the temperature of the environment is lower than skin surface temperature, the transfer of body heat by conduction, radiation and convection to the environment will cause a thermal equilibrium without necessitating a rise in body temperature. When the temperature of the

environment rises above an upper limit, sufficient heat transfer by conduction, radiation and convection becomes impossible. Heat transfer is still possible if the environment is able to accept water vapour so that the heat may be dissipated by evaporation. This means that in a hot, humid environment the limit would be established by the maximum capacity of the atmosphere to take up moisture from the skin, while in a hot, dry environment, the limit is more likely to be determined by the capacity of the body to perspire. (Bazett, 1949).

As the temperature rises, production of sweat increases to rise the heat loss. Evaporation of sweat depends on the vapour pressure of moisture in the atmosphere, the clothing and air velocity. In general the evaporation potential is greater the lower the vapour pressure and the higher the air velocity.

When the air temperature is lower than skin temperature, any increase in air movement will result in a great heat loss by convection. When air temperature is higher than skin temperature, the increase in convective heat exchange warms the body, but at the same time increased air velocity will increase the evaporative capacity and consequently the cooling efficiency. (Adolph, 1947; Givoni, 1976).

However, sweat is necessary in a hot environment for keeping cool. The practical control of sweat expenditure depends upon realization of the factors which increase or decrease the sweat required. To reduce sweat, one must avoid the heat gain from either the surroundings of the body or the body's own heat production. Leithead and Lind (1964) noted that "the ingestion of food and drink can play some part in affecting the severity of exposure to heat." During the heat, man should refrain from taking foods that contain protein or salt (Adolph, 1947). Therefore in Egypt it is usual to eat light food, vegetables and fruits containing water, such as watermelon, are preferable during lunch.

In a hot, dry climate, low humidity may cause unpleasantness because of excessive dryness of the lips and mucous membrans in the upper respiratory tract (Givoni, 1976). On the other hand, it becomes possible

to drink more water because of the dryness, causing more secretion of sweat and giving increased evaporation. Thus it is very common in Egypt to see water jars in different places in the streets. These are called "sabil", which means that the water is free for everybody. See Figure 3.5.1.



Figure 3.5.1 This jar is placed in the shade. From its pores a certain amount of water seeps through constantly for evaporation. This evaporation cools the remaining water. (Fathy, 1973)

3.6 CLOTHING IN A HOT CLIMATE

To some extent the heat gain by radiation is influenced by the colour of clothing as well as the texture of its surfaces and the design of

the clothing. The white clothes worn in hot environments keep their bearer cooler in the sun than the same clothes in black would do. The texture of the clothing affects its reaction to the wind velocity, thus affecting losses by convection (Forbes, 1949).



Figure 3.6.1 Traditional clothing design in hot environment.

Clothing in a hot climate may act as a barrier to the convective and radiative heat exchange between the body and its environment (Givoni, 1976). Kerslake (1972) states that using loose clothing in a warm environment will permit as much penetration by ambient air as possible. In this case the radiation does not pass through the clothing. The skin loses heat by convection to the air and by radiation to the inner clothing surface. Some of the heat will be lost by convection and the remainder will pass through the clothing to its outer surface and thence to the environment by convection and radiation.

Effective ventilation in hot-climate clothing is a distinct advantage in keeping men cool. Clothing made with open collars and cuffs and large openings in both sides of the gown is found to aid ventilation appreciably (Figure 3.6.1).

Clothing is usually made of cotton material to absorb the sweat from the skin. The evaporation can occur either from within the fabric of the clothing or from its surface. In either case the total rate of evaporation required for thermal balance is increased (Forbes, 1949; Robinson, 1949).

3.7 COMFORT ZONE

Mather (1974) has pointed out that many studies of human comfort have been undertaken to study the reaction to different combinations of climatic conditions by a large number of people of different ages and sexes, dressed in various clothing assemblies and exposed to both indoor and outdoor conditions. All investigations realize the difficulties in such experimentation, yet all agree that the results obtained are valid and useful.

From the thermal standpoint, comfortable air conditions are those under which a person can maintain a normal balance between production and loss of heat at normal body temperature and without sweating (Yaglou, 1949). Straaten (1976) has pointed out that, "Obviously, somewhere between the extremes of inevitable body cooling and inevitable body heating must be a point where the body has to take no appreciable physiological action to maintain its heat balance. This point may be considered as the point of optimum thermal comfort for any given set of conditions. Furthermore, the conditions for optimum comfort will not be the same for every individual, depending on many factors as mentioned before, such as reaction to environment, clothes, health, etc. It is therefore general practice not to specify a point of optimum thermal comfort, but rather to define a range of conditions of a so-called comfort zone."

Koenigsberger and Ingersoll (1974) have described comfort zone as the range of conditions within which at least 80% of people would feel comfortable.

Yaglou (1949) has mentioned that no comfort standards can be fixed to apply under all conditions although it is possible to establish limits which will meet the requirements of a majority in any given homogeneous group under certain conditions. The factors determining selection are largely individual, owing to wide biologic diversity and variable response of different persons to a given physical environment. Climate and season, activity, clothing, etc., and degree of adaptation are among the important modifying factors. For men and women at rest and dressed according to season, the acceptable range of temperature usually is between 18 to 24 °C in cold weather and between 24 and 28 °C in warm summer weather.

In general Saini (1973) has mentioned that Campbell has arrived at an "average figure of 29.4 °C dry bulb temperature as the upper limits of comfort which may be considered for a minimum standard of design." These upper limits were mainly based on experiments in hot regions where humidity is high. In a hot, dry land where there is no humidity problem, this figure could be higher.

The ordinary variation of humidity within the comfort zones temperature have little effect on evaporation of moisture from the skin and on sensations of comfort. Evaporation from the skin, within this temperature range, is limited to the amount diffusing through the capillaries. This amount remains substantially unaffected by humidity. As the temperature rises beyond the comfort point, active sweating begins, and the rate of sweat secretion is controlled by requirements for body heat balance.

When evaporative cooling is intended to be used, humidity becomes increasingly important in determining the rate of sweat secretion and evaporation, as well as the feeling of thermal comfort or discomfort.

When the external temperature approaches or exceeds that of the body's surface, humidity becomes the most important of all environmental factors (Yaglou, 1949).

Figures 3.7.1 - 3.7.4 show some charts of thermal comfort in different air velocities (Markus and Morris, 1980).

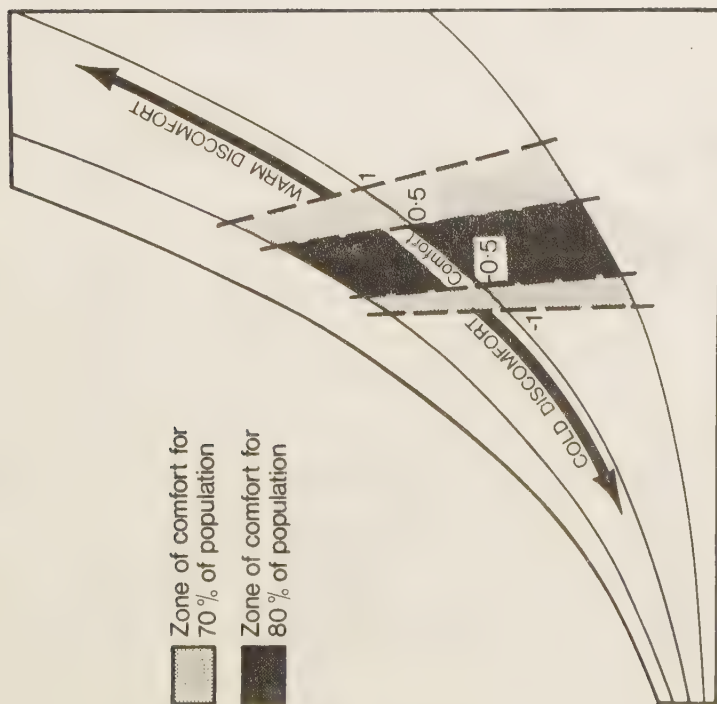


Figure 3.7.1 Chart of thermal comfort. (Markus and Morris, 1980)

Activity taken as sitting
 $1 \text{ met} = 58 \text{ W/m}^2$

Thermal resistance of clothing
 $\text{Clo unit} = 0.155 \text{ m}^2 \text{ } ^\circ\text{C W}^{-1}$

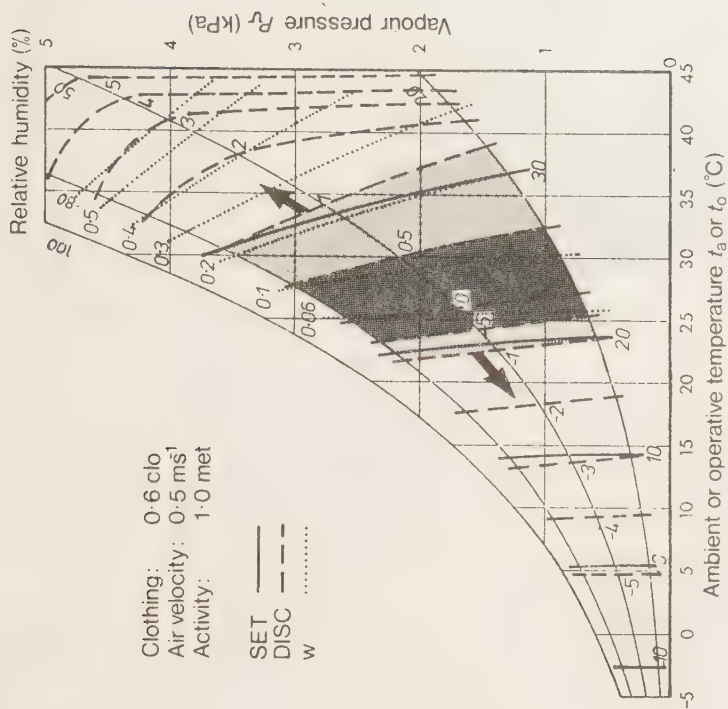


Figure 3.7.2 Chart of thermal comfort. (Markus and Morris, 1980).

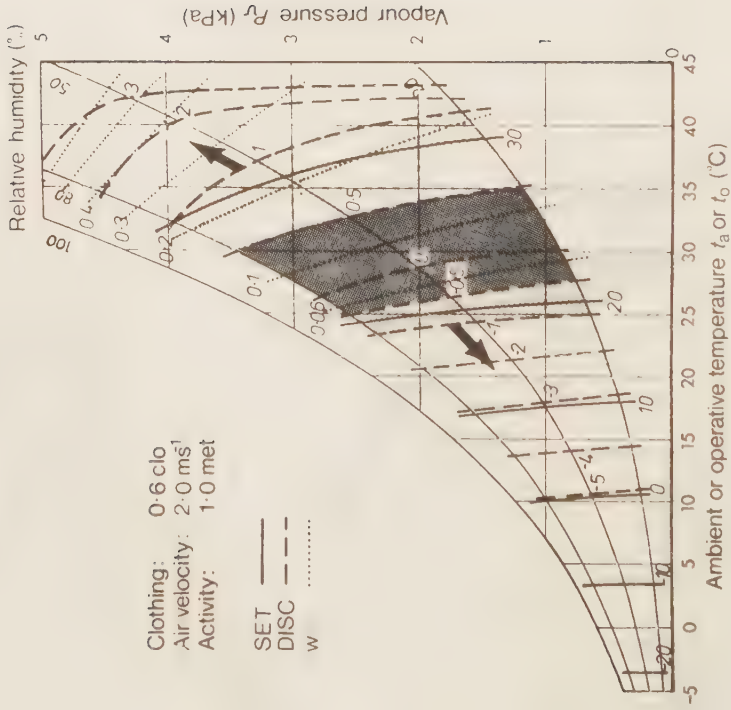


Figure 3.7.3 Chart of thermal comfort. (Markus and Morris, 1980)

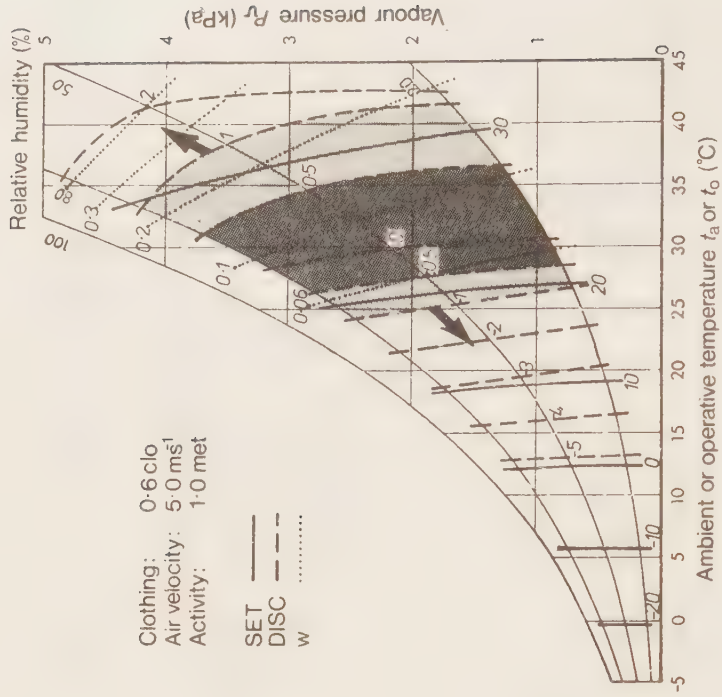


Figure 3.7.4 Chart of thermal comfort. (Markus and Morris, 1980).

4 AN ADAPTATION OF SHELTER FOR THE ENVIRONMENTAL CLIMATE OF EGYPT

Traditional methods are still used in a large part of rural building today. Some of the advantages of traditional materials are their availability, low cost, resistance to the climate and familiarity to local skilled labour in both construction and repair.

There are many useful ideas to be found in the building of traditional types of houses which can be re-evaluated in terms of modern technology and which benefit our homes by achieving a more comfortable indoor climate without mechanical means.

Egyptian history falls into three parts: the period of Egypt's independence, from prehistoric time to the death of Cleopatra in 30 B.C.; the period of Roman and Byzantine domination from 30 B.C. until the Arab conquest of the country in 639-640 A.C.; and the Islamic period from the Arab's conquest until present day (Wulsin, 1949). Houses built within this period in Egypt are here denoted Islamic houses.

It may be necessary to mention here that Islamic civilization was not uniform nor was it enveloped by any culture. This of course depended very much on its geographical location and climate, so that the houses took on quite individualistic characteristics according to their location.

In this chapter the general form of the building and its site according to climatic conditions as well as the general characteristics of the plan of the house and its function are described. The common material used in this type of houses is also discussed. To understand how the structure protects the occupants from the external heat, it is necessary to know the various components of the building, i.e. the walls, roof, floor and windows, and finally the cooling system, which is used to regulate the indoor temperature.

4.1 BUILDING FORMS AND CHARACTERISTICS OF THE HOUSE

The first level of adaptation to the climate is that of determination of the mass of the building, the important relationship between the volume of the building and the space enclosed (Abdulak and Pinon,1973).

It can be seen from Figure 4.1.1 that one building can have more than one courtyard, depending on the size and function of the building. The functions of the space between the building volumes are to permit the building volumes to protect each other from direct solar radiation and to give shaded walls, and at the same time to allow the wind to penetrate through the building volumes to cool the structure during the night.

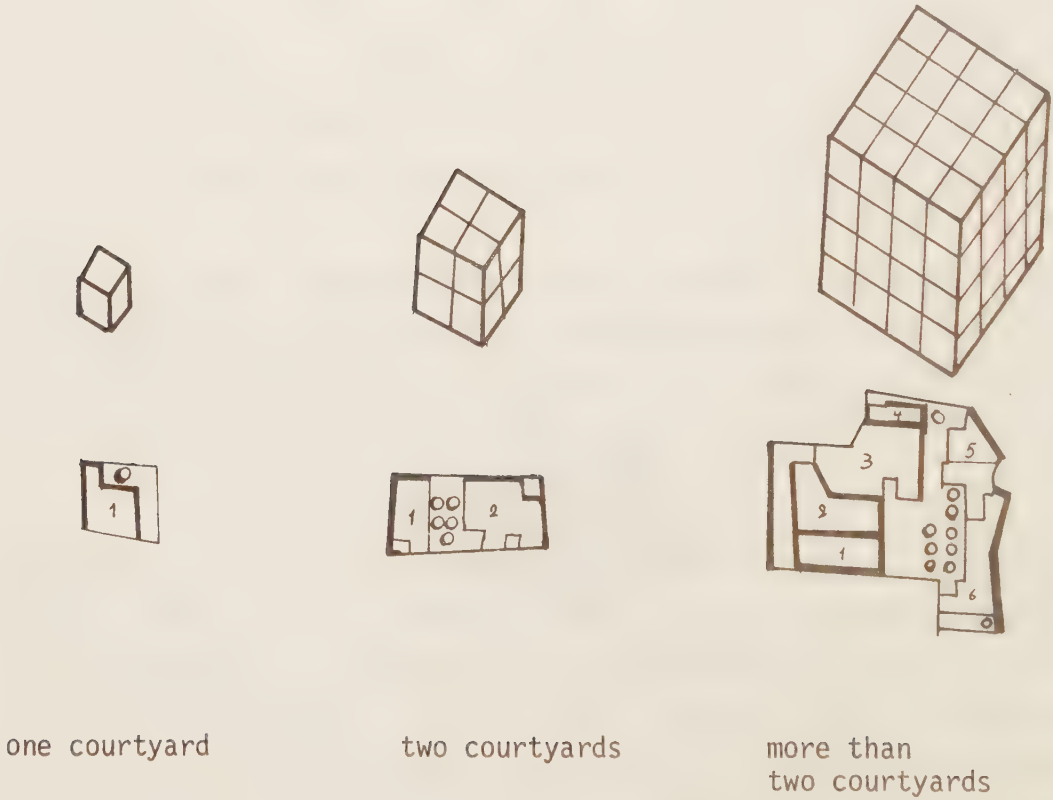


Figure 4.1.1 The relationship between volume of the building and the space enclosed. Source: Abdulak and Pinon, 1973).

Compact layout and a narrow street will provide maximum volume with minimum surface area exposed to direct solar radiation. In a narrow street, a person can walk even at noon in the shade.

When houses open toward the sea, they exploit the sea breeze for cooling during the hot season, see Figure 4.1.2. Rapoport (1969) noted how the site of buildings took into consideration the local wind pattern, movement of hot and cold air, shade and sunny spots and their relation to the seasons. Landsberg (1978) has also stated that "The Arabic section is opened toward the sea Thus, natural conditions are used for climatization, an aim which can be attained by taking local climate into consideration."

After Amr Ben Ass conquered Egypt (641/2 A.D.), he made a plan for the construction of Fostat city in 21 H, which can be used as an example of the construction of the early Muslim period (Creswell, 1959). A study of the remains of Fostat city makes it clear that these houses all shared many similarities. In the center of each house is an open courtyard which is square or rectangular in shape, of varying dimensions and proportional to the building (Figure 4.1.3).

A passage with a right-angled turn generally leads from the entrance to one of the side bays so that it is not possible to look into the courtyard from the street, see Figure 4.1.4.

After the settlement of the Arabs in Egypt they succeeded in adapting a more progressive and exciting form of architecture, as seen in the buildings of mosques and civil habitations.

The following will describe some general planning of private houses after the Arabs settled in Egypt which considers the climate variable.

The general planning of private houses in Egypt was, of course, quite varied, depending on the social class of the inhabitants and the function of the building (Crace, 1870).

Before analyzing these buildings regarding their climatic variables (which is the main object of this study), I will give a rather general



Figure 4.1.2 The houses opened toward the sea and wind catches on the roofs make use of the sea breeze for ventilation of the buildings. (France, 1809)

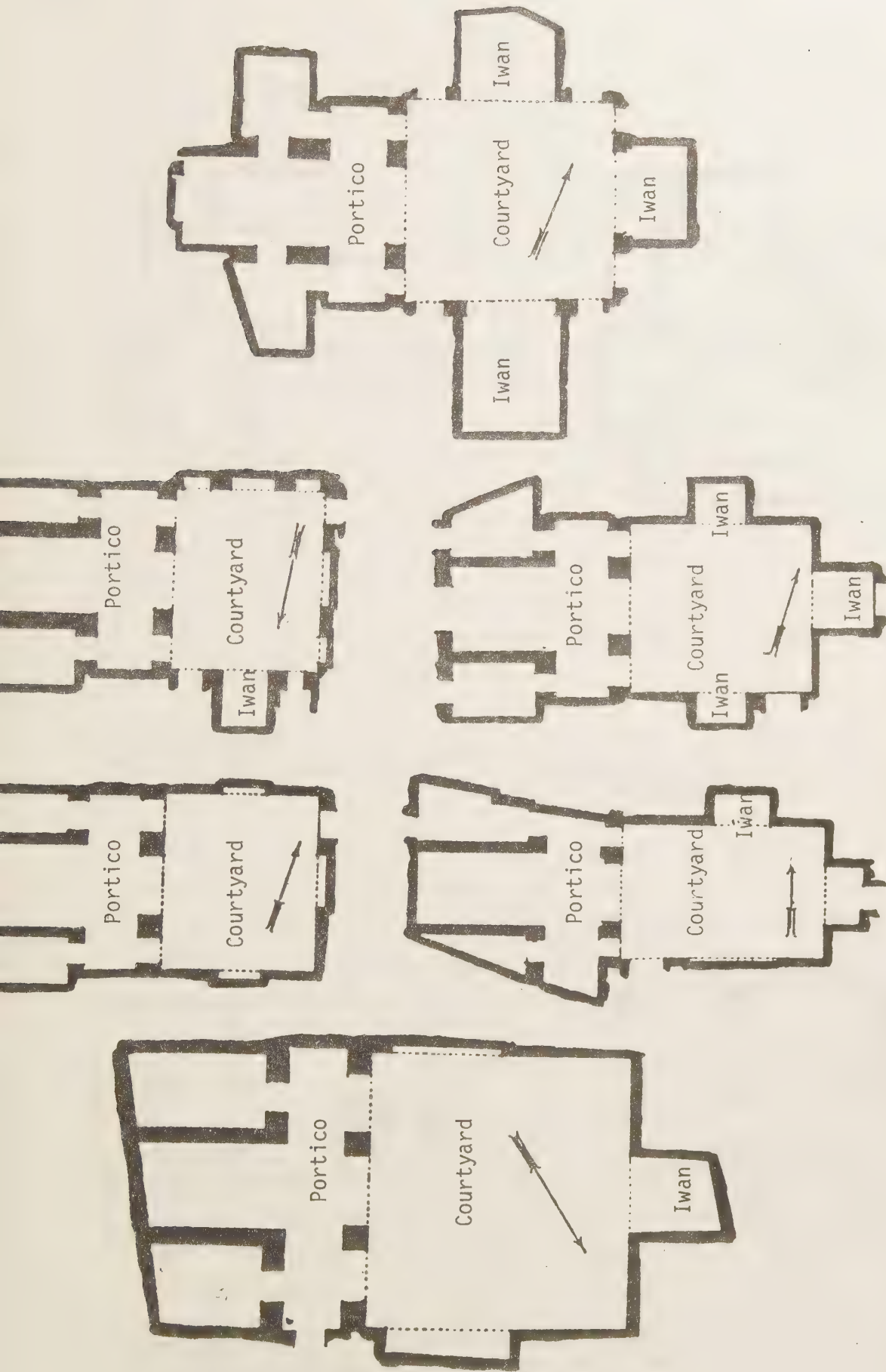


Figure 4.1.3 The Fostat houses, in the center an open courtyard, with the main axis parallel to direction of prevailing wind. Scale 1:200. (Creswell, 1959).

First floor plan



Figure 4.1.4a Ground floor plan of House El-Sinnari. (Revoult and Maury, 1975).



Figure 4.1.4b Section of the Sinnari house S_1-S_1 , showing wind catch on top of the roof. (Revoult and Maury, 1975).

description of the building's plan and functions to show which elements or conceptions of the different parts of the house were designed because of social aspects and which were built to react to the climate.

Count (1890) has defined the principles on which houses in Egypt were planned as being:

- the grouping of the rooms around the courtyard
- absolute separation of rooms for each sex
- preventing passers-by from seeing into the courtyards
- in general no windows facing the street. If these existed, they were positioned at a height such that a man on horse-back could not look into the interior. No window permitted a view into another house or apartment.
- the arrangement of rooms, kitchens, baths, to take advantage of the prevailing breezes and construction of ventilators (Malkaf) to air the rooms.

Poole (1886), Lane (1838), Jones (1920) and Crace (1870) have characterized Egyptian houses by the following functions:

The external texture of the house: the walls to the height of the first floor are built of stone. The second floor projects out about 0.6 m from the main structure and is supported by stone corbels. It is made of brick and plastered. From this projection yet another projection is built on; this is a bay-like construction which protrudes another 0.45 m and is made of latticed wood. It is called 'Meshrabeyh'.

The entrance to the house is through a more-or-less narrow dark vestibule, which always forms one or two angles to prevent seeing into the courtyard. The rooms most accessible from the courtyard, on the ground floor, are those which belong to the men of the household. These include the stables, storerooms and the rooms in which the master receives his male guests (Poole, 1886). The main reception room is called the mandarrah and there are two living spaces, the makad and the takhtabosh. The last two are mainly for use in the summer and the first is a gen-

eral salon for men.

The Takhtabosh is a square open hall, facing north and furnished on three sides with wooden benches. The ceiling is of wood fretwork in natural wood colour. It is supported by a single column and the floor is paved with stone. Not every house has a takhtabosh.

The Makad is a belvedere or open gallery on the cool side of the courtyard. It has an open front with two or more arches and a low ceiling. It is plainly furnished, like the Takhtabosh, and is a pleasant lounge for the men in hot weather.

The Mandarrah is the men's principal room, in which male visitors are received. It has one or two wide, wooden-grated windows. The floor is in two levels, the first part smaller and about 0.15 m lower than the rest. This part is called the durkaah. In rich houses, the durkaah of the mandarrah is paved with white and black marble and small pieces of red tile inlaid in complicated and tasteful patterns. In its center is a fountain called 'Faskeeyah'.

The raised part of the floor in the mandarrah is called 'Leewan'. Lane (1838) has noted that "The leewan is generally paved with common stone and is covered with a mat in the summer and a carpet over the mat in winter." This mat can be dampened during the hot weather to give cooling by evaporation. Mattresses and cushions are placed on the leewan against each of its three walls. The mattresses are generally about 90 cm wide and 10 cm thick and are placed on the ground.

The walls generally contain two or three shallow cupboards made of wood, the doors of which are composed of very small wood panels because of the warpage and shrinkage which the hot, dry climate causes in wood (Lane, 1838).

The upper apartment usually consists of the rooms for the family. Among these rooms there is a large room called Kaaha. This room has two leewans. In general all the rooms in the apartment are lofty, 4.50 meters high, but the kaaha is the largest and highest room. It can be noted that none of the chambers are furnished as bedrooms; In

the daytime the beds are rolled up and put to one side of the room or in an adjoining closet called "Khazneh".

The roofs of many houses have a wind catch, called "Malkaf", which is directed toward the north or northwest, to convey the cool breeze into the apartments below.

It is impossible to generalize about the actual arrangement of rooms, as each plan can vary greatly. For example the kaaha and mandarah may rise to the full height of the house. This gives an advantage in protecting the occupants from the heat of the ceiling and allows the hot air to escape upward.

In general the house is designed to be as private as possible and the rooms are constructed around the courtyard. Their location depends on the position of the sun and direction of the prevailing wind.

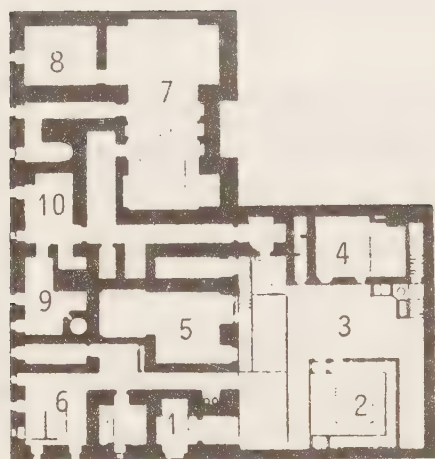
In Figure 4.1.5 plans of an Islamic house in Cairo are shown. They follow the principles discussed above.

4.2 BUILDING MATERIAL AND PRODUCTION

The nature of the building material employed in any country depends upon many factors, the principal of which are the climate, the degree of civilization of the people and the kind of materials available. The architecture of Egypt is characterized by the use of clay and stone. These materials are abundant and readily accessible.

In the following the common materials which are used to construct walls and roofs of traditional buildings in Egypt, are described.

BRICK: Brick-making was known to most ancient cultures. The oldest bricks were found in upper Egypt (Aswan) and sun-dried brick is still the characteristic building material in villages and smaller towns. The bricks are made of Nile alluvium or Nile mud, which is a mixture of clay and sand containing small amounts of impurities. The properties



Ground floor



First floor

- | | |
|---------------------------|-------------------------|
| 1 = Entrance | 10 = Kitchen |
| 2 = Summer room (makad) | 11 = Stair to open hall |
| 3 = Courtyard | 12 = Stair to harem |
| 4 = Service room | 13 = Open hall |
| 5 = Mandarah (guest room) | 14 = Takhtabosh |
| 6 = Stable | 15 = Guest rooms |
| 7 = Chief mandarah | 16 = Rooms (harem) |
| 8 = Service to mandarah | 17 = Kaaha |
| 9 = Bake-house | 18 = Open courtyard |

Figure 4.1.5 A house in Cairo. (Poole, 1886).

of the mud depend on the plasticity and cohesiveness of the clay. When the percentage of clay is high, the mud is sufficiently tenacious to cohere without any extraneous material. When the percentage of clay in the mixture is too high, the bricks made from it will shrink during drying, crack and lose their shape. In order to prevent this, alluvium is mixed with sand or chopped straw, which is also added sometimes as a binder when the proportion of clay is low (Flinder 1938). To increase plasticity of the clay, peat or other organic material is added. In the lower desert, yellow brick can be made from the local clay with no Nile mud added to it.

The method of making brick is known from the models of tombs dating from the Middle Kingdom. The hard mud was broken up with a hoe, mixed with water and kneaded with the feet until it was of the right consistency. It was then carried to the brickmaker, who placed the mud in a wooden mold or form which the brickmaker then lifted, leaving the brick on the ground to dry in the sun.

The houses constructed with sun-dried bricks are cheap and very suitable for warm climates where rain is very rare.

The bricks differ considerably in size, some being of much the same dimensions as modern brick while others are very large.

Fired bricks were known from a very early date, but were not employed generally in Egypt, as far as is known, until the time of the Roman occupation. At present there is wide use of different types of brick.

STONE: "Egypt is the home of stone-working and possesses both the oldest and largest stone building in the world." (Lucas, 1962).

The use of stone on a large scale is due to the fact that the country is very rich in stone. The most common stones used in Egypt for building are limestone, sandstone and, to a much lesser extent, granite, with the occasional use of alabaster, basalt and quartzite.

LIMESTONE: consists of calcium carbonate (carbonate of lime) but sometimes contains small proportions of other components such as

silica, clay, iron oxide and magnesium carbonate. It differs considerably in quality and hardness. It is found extensively in the hills bordering the Nile Valley from Cairo to Esna (southern Egypt) (Lucas, 1962).

SANDSTONE: consists essentially of quartz sand derived from the disintegration of older rocks, cemented together by very small proportions of clay, calcium carbonate, oxide of iron or silica. As already mentioned, the hills bordering the Nile Valley from Cairo to near Esna are made of limestone, but beyond Esna this limestone is replaced by sandstone, which forms the hills on both sides of the river until Aswan (Lucas, 1962). In general the stone has a very high heat-storage capacity. It is a dense material with high resistance to mechanical damage and destructive climatic effects. It is unaffected by rain but becomes damp with continuous rain and also varies in colour.

MORTAR: Two kinds of mortar were employed in ancient Egypt, clay for use with sun-dried brick and gypsum or limestone for use with stone.

CLAY MORTAR: "-Is simply the ordinary Nile alluvium consisting of clay and sand, which is mixed with sufficient water to bring it to the required consistency, sometimes with the addition of a little chopped straw. This mortar is still being used for sun-dried brick at the present time and is the most suitable material for this purpose." (Lucas, 1962).

GYPSUM MORTAR: is used for stone. It is necessary to burn and slake the gypsum before it is used. Gypsum is not now employed as a mortar, having given place to the more recent lime-sand mixture or to the even more modern material cement.

LIMESTONE MORTAR: is very common in Egypt, even more than gypsum and also more accessible.

CEMENT MORTAR: is at present used for fired brick. It contains a varied proportion of sand, lime and cement.

PLASTER: The plaster which was used in traditional buildings was similar in composition to mortar and consisted of the same materials, namely clay and gypsum.

CLAY PLASTER: was generally mixed with chopped straw. On a wall which was exposed to rain, the plaster had a higher proportion of sand and was the same kind of plaster used for the sun-dried brick. A better quality of plaster is given by natural mixture of clay and limestone.

GYPSUM PLASTER: is used mainly to provide the walls and ceilings of the house with a suitable surface for painting. Where the walls were plastered with clay, these were then coated with gypsum plaster. Where clay plaster was not used, the gypsum plaster was employed for the purpose of covering up faults and irregularities in the stone and smoothing the surface before painting began.

Gypsum, being a natural material, varies considerably both in colour and in composition. The colour may be white, different shades of grey, light brown or even occasionally pink. "Chemically, gypsum is calcium sulphate (sulphate of lime) containing water in intimate combination. On being heated to a temperature of about 100 °C, gypsum loses about three-fourths of its water and forms a substance which has the property of recombining with water to produce a material that sets and finally becomes very hard." (Lucas, 1962).

WOOD: Egypt is not suitable for wood production and it has been necessary from very early times to import a portion of the wood required. In traditional old houses wood was used for doors, windows and roofs, and occasionally for furniture. Several smaller native trees can be found in the country such as:

The date palm (Ar. Gereed), which was widely used, the trunk serving as columns and beams and the leaves and branches being important primary materials. The date palm is an important element in the Egyptian environment. The tree has a small, high head that gives shade and at the same time does not obstruct the wind or prevent the sunlight from reaching crops below. It is ideally suited to Egypt's ecological conditions and it grows best with its roots deep in damp soil. Finally,

its fronds are used for roofing and mats.

The sycamore fig (Arabic "Gemmeiz") is a much-used soft wood. It grows into a very large tree and provides shade in many of the villages.

The acacia (Arabic "Sant") is still used for boat-building. In ancient times it was sometimes used for roofing and to strengthen the wall. Because of high diurnal variation in temperature in the hot climate. it was used after several courses of brick as a wood girder to give flexibility to the wall so that it would not crack.

The sidder (Arabic "Nabk"), a small and usual spread tree, has a hard and durable wood and was used mainly in joinery.

Imported wood was needed only for exceptional circumstances, as in roofs of large span, for example (Lucas, 1962).

4.3 THE IMPACT OF THE ENVIRONMENTAL CLIMATE ON ELEMENTS OF THE HOUSE

THE WALLS: The function of the outer walls in old traditional buildings was simply to hold up the roof and separate the indoor space from the external environment.

The hard desert soil was firm and stable under normal conditions and it formed an excellent base for foundations. On the other hand, alluvium is a very unstable material and causes uneven settlement of the building and subsequent fracturing, a condition which is emphasized by the annual rise and fall of the water table. Furthermore, the moisture which rises in walls and floors causes humidity within the buildings and injury to the walls, with efflorescence of salts and disintegration of the stone. On alluvial soil, however, a layer of sand about 40 cm thick was laid in the foundation trenches so as to provide a firm and even bed for masonry (Clark and Engelbach, 1930).

Temperature stresses are very great in the desert. The temperature of exposed rock may vary by 37 °C between day and night, dropping suddenly after sunset. The alternation of expansion and contraction is an

important factor in the weathering and disintegration of rocks in the desert landscape. To prevent longitudinal cracking of walls from shrinkage or temperature stresses, the Egyptians inserted grids of timber or mats of reeds in their thick mud-brick walls (Clark and Engelbach, 1930). Long walls are sometimes constructed in sections with concave, convex, or level courses alternating, so as to allow for expansion and contraction under the great diurnal temperature variations (Clark and Engelbach, 1930).

The foundation walls are about 0.6-1.0 m thick to the height of the first floor. The thickness is determined by the shape and size of the stone used. When the stone is cut in regular form, the thickness of the wall is not more than 0.6 m. When the stone is cut irregularly, the wall can be about 0.8-1.0 m thick. The type of construction and the materials used in the traditional methods caused the wall to be very thick.

The second floor of the house was constructed of sun-dried or fired brick. The walls were about 0.25 m thick; timber beams were inserted between the courses of brick to prevent shrinkage.

The external surface was plastered with a mortar composed half of mud, one-fourth of lime and the remaining part of ashes. The internal surfaces were usually covered with tiles to the height of 1.5 m and the rest covered with cement mortar or "gebs", then coated with lime colour (Lane, 1838).

Usually the external wall is shaded by the narrowness of the street or by an overhanging form or a balcony. This kind of shading protects the external wall of the building from direct solar radiation.



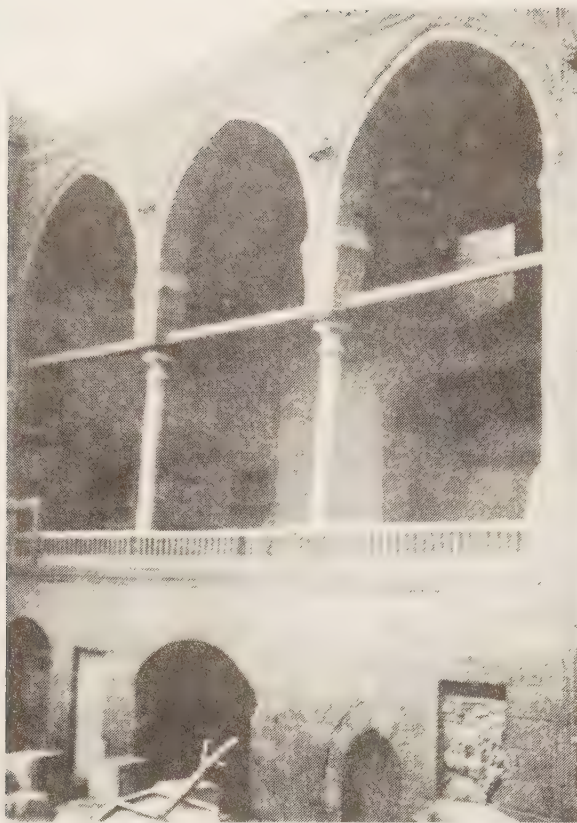
Figure 4.3.1 The second floor is constructed of sun-dried mud bricks with a timber beam inserted between the courses to prevent the wall from shrinking. The figure also shows that the second floor is built with a thinner wall and shaded by another building. (Revoult and Maury, 1975).



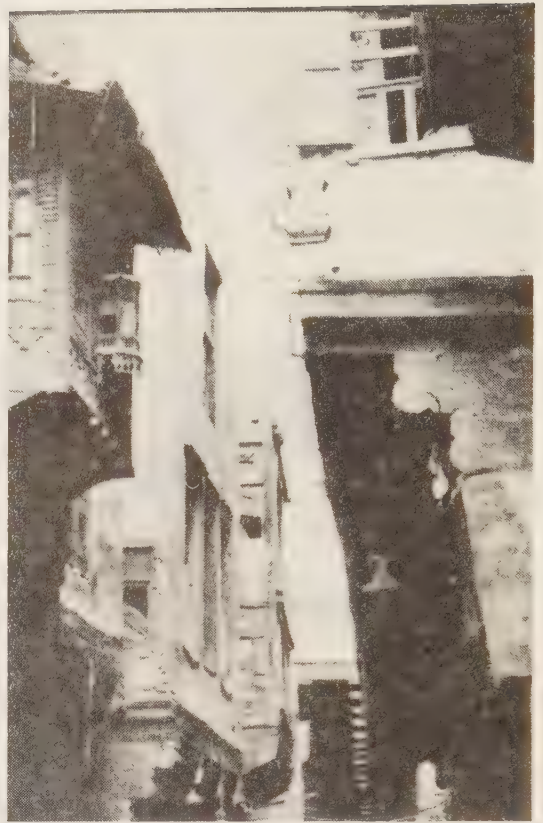
Figure 4.3.2 The second floor usually projects about 0.6 m to the front. This projection is carried by corbels made of stone or timber. (Revoult and Maury, 1975).



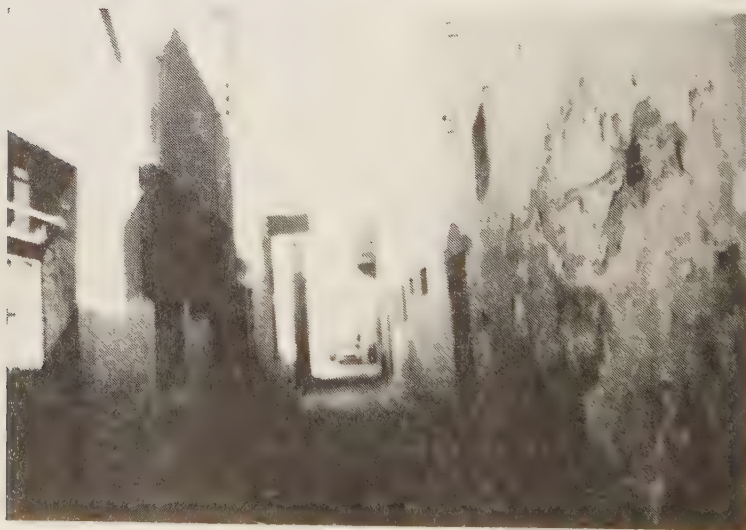
Figure 4.3.3 The structure is wall-bearing. Therefore the first floor has a thick wall made of stone and the second floor a wall of thin sun-dried mud brick or fired brick which is then plastered. (Lezine, 1972).



a) (Lezine, 1972).



b) (Jones, 1920).



c)

Figure 4.3.4 a) The wall of the house can be shaded by a balcony which is also used as a sitting-room and for sleeping in summer.
 b,c) The streets are narrow so that one building shades the other. In a narrow street a person can walk in the shade even at noon.

a)



b)



Figure 4.3.5 a) Cupboards in the wall of the second floor. These have the function of wall insulation and can be opened at night to replace the day's hot air by cool air from the night. (Revoult and Maury, 1975)

b) The wall can be cased with marble or tile to a height of 1.5 m which permits it to lose heat rapidly. (Revoult and Maury, 1975).

ROOF AND CEILING: In traditional building roofs were usually flat, but vaults and domes have also been used since antiquity. One of the concepts back of dome roofs was to give the effect of the sky when seen from the inside. The dome was often perforated with small holes which were then filled with pieces of coloured glass which simulated stars in the sky (Count, 1890).

Another concept was that because of the rarity of wood in this area, the roof was constructed as a dome or vault, made of brick or stone and built without any framework.

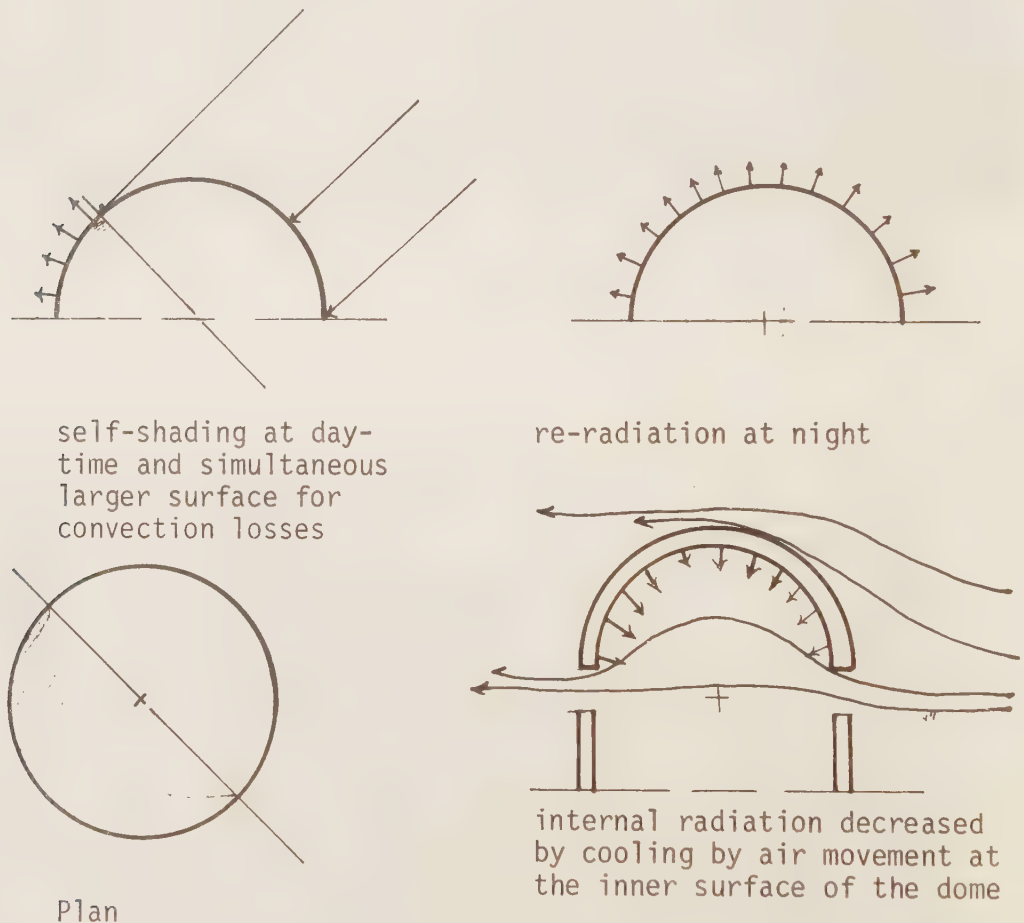


Figure 4.3.6 The function of the dome shape in a hot climate, reacting against external heat.

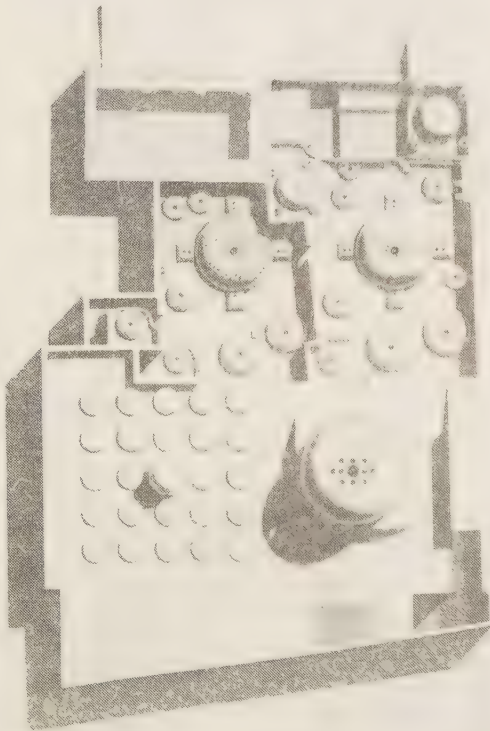
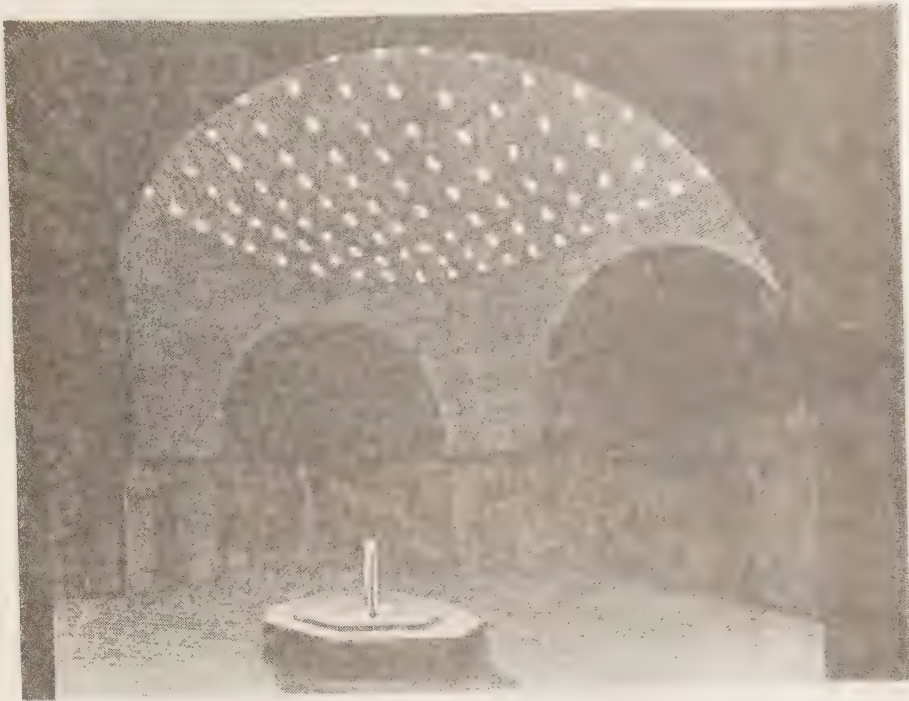


Figure 4.3.7 A fountain which cools the surrounding air is found under the dome; Consequently, the hot air rises up and escapes through small openings near the ceiling.
Source: France, 1809

a)



b)



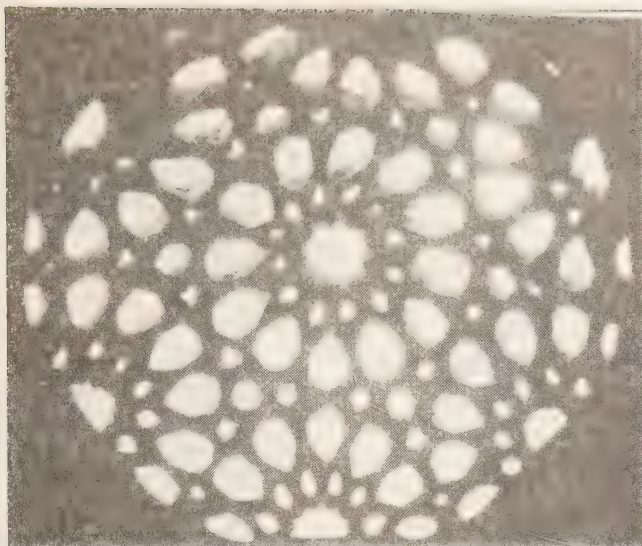
c)



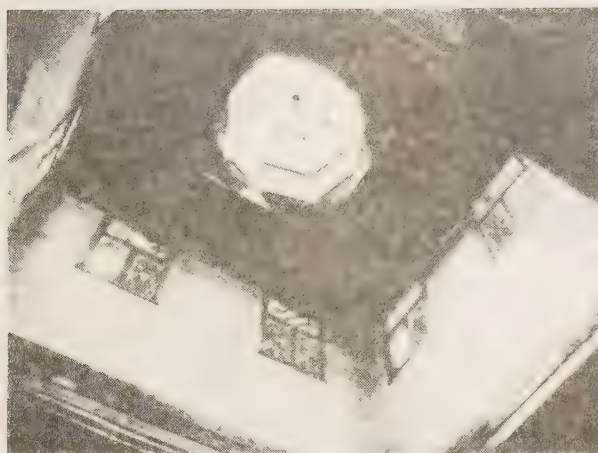
(Creswell,
1965).

Figure 4.3.8 a)-c)

d)



e)



f)



Figure 4.3.8 d)-f) d and f (Creswell, 1965), e (Lezine, 1972).

g)



h)



i)

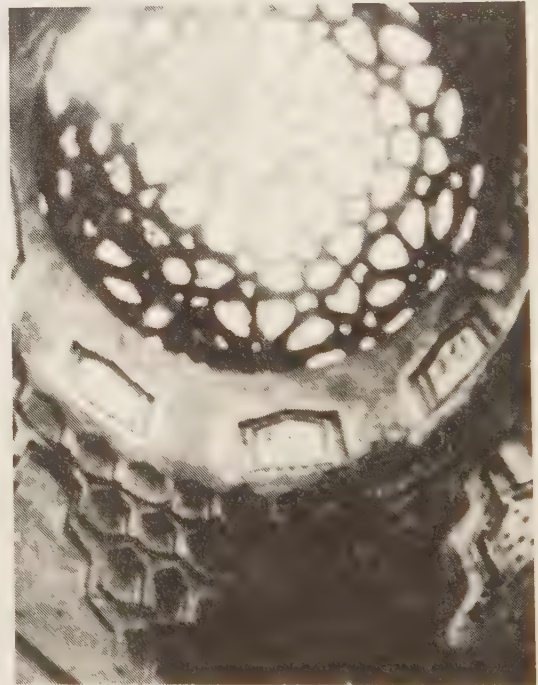


Figure 4.3.8 g)-i)

Figure 4.3.8 Different forms of domes give different height of ceiling. Windows are made in the neck of the dome to remove hot day air under the ceiling before it reaches the occupants.

The dome is perforated with small holes which are filled with pieces of coloured glass which were to simulate stars in the sky.
(Creswell, 1965).

Flat roofs were usually constructed of timber. To insulate them against the heat, the traditional method was to lay empty jars against each other. The air contained in these jars acted as an insulation layer.

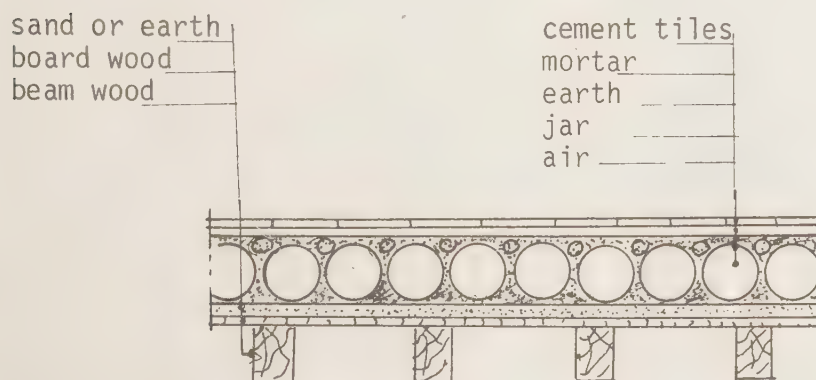


Figure 4.3.9 Detail of flat roof made of timber

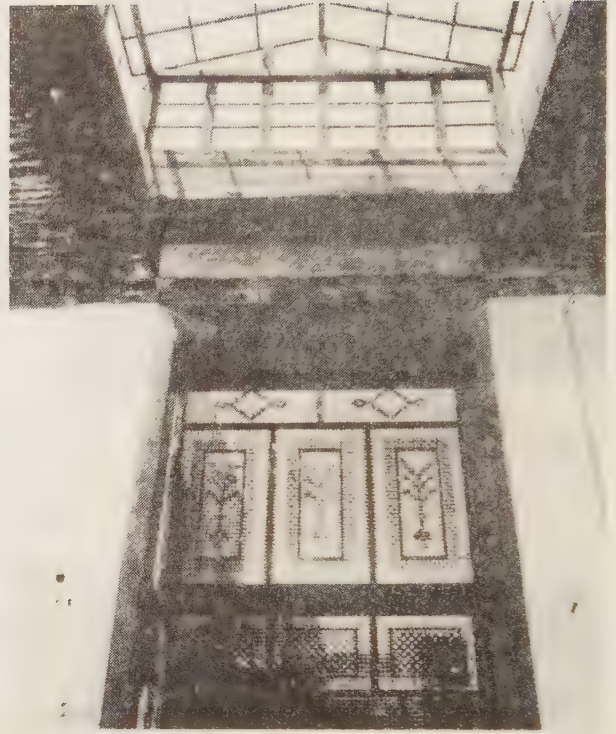
In general the flat roof is an important part of the house where people can sit to work in a shady place open to the breeze. White or other light colours are used on the upper surface to reflect the sun's radiation. Flat roofs can be shielded from the direct rays of the sun by a pergola or trellis covered with light matting. Apart from cooling the air above the roof, the roots of such growth preserve a certain amount of moisture which not only helps to keep the temperature down but prolongs the life of the roof by minimizing cracking in extreme temperature variations.

As the roof is a major source of heat gain in a building, intense solar radiation generates considerable heat on the roof surface during the day and transmission raises the temperature of the ceiling surface.

FLOOR: The flooring of small houses consisted simply of a layer of beaten mud laid over the ground. In larger houses, the substratum was of brick which was then paved with tiles. In areas where the soil was damp this floor rested on a platform constructed of a series of cylindrical earthenware jars which were closed at the top to form a flat surface. These were then sunk vertically into the ground under the



a)



b)

Figure 4.3.10 Flat roof constructed of wood. The ceiling height is about 4.5 m. Even though the room has a large window, there is also a high opening near the ceiling for ventilation and removal of hot air under the ceiling. (Lezine, 1972).



Figure 4.3.11 The floor in two levels; The first broke the longitudinality of the room and the second bounded the entrance and sitting area. Usually the part before the door is smaller and about 0.15 m lower than the rest. The floor can be paved with marble or cement tiles. (Lezine, 1972).

flooring. (Peet, 1923, Lucas, 1962).

Mud floors were often dampened to stabilize the dust which formed on the surface. A fresh coat of mud was added regularly.

Stone and concrete floors were durable and resistant to heavy wear. When shaded they felt cool to the bare foot; The cool floor is linked with traditional style where people recline on cushions on the floor. Lane (1838) has also mentioned that floors of marble or stone were left bare in the summer and covered by carpets in winter.

WINDOW: In warmer climates the window plays an important role in controlling the indoor temperature. Saini (1973) mention that window area in hot climates should be kept to a minimum to give only an adequate natural lighting. In Egypt, however, most of the old houses have large windows. When Lane (1838) described the Islamic houses he said that "The ground floor apartments next the street have small windows placed sufficiently high to render it impossible for a person passing by in the street, even on horseback, to see through them.... The windows of the upper apartments are generally large and project about 45 cm or more and are formed of turned wooden lattice-wood."

The function of the window is to admit light, provide ventilation and a view while limiting the entry of undesirable elements of the outdoor environment. The special function of a window in a hot, dry climate, where the summer heat is the main source of discomfort, is to admit light without admitting direct sunshine.

Lattice-wood not only reduces the quantity of light and sun rays which penetrate indoors, but also screens the inmates of the house from the view of persons outside, while at the same time it admits the air. (Lane, 1838). This lattice wood is normally left unpainted, but sometimes is painted green. Windows of this kind are called "Meshrabeyh". Some projections of lattice-work are furnished with frames of glass on the inside, which are closed in the winter.

Glare is often a problem when large unshaded windows are used. One way to control the sky's brightness and glare is by reduction of the

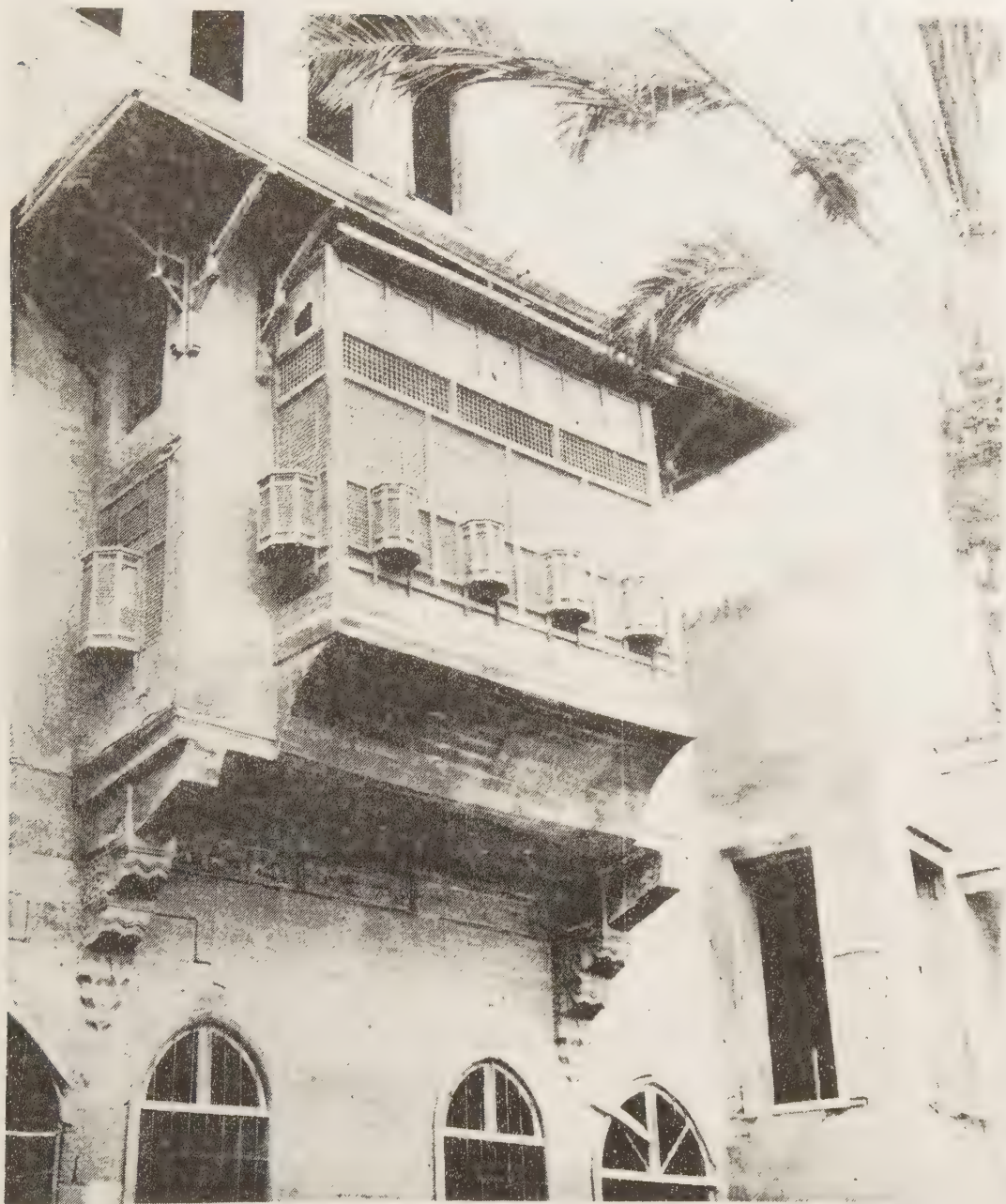


Figure 4.3.12 The second floor projects from the main structure about 0.6 m and is supported by stone corbels. It is made of brick about 0.25 m thick and plastered. From this projection there is yet another projection made of lattice-wood to admit air from all directions. (Revault and Maury, 1975).

size of the openings, which reduces the sunlight. This method is used in building in desert areas. Reduction of window size, though limiting the entry of light, does not entirely solve the problem of glare, which can in fact be worse because of the contrast between the light opening and the surrounding surfaces. Saini (1973) noted that "The Islamic period solved this problem by use of Meshrabeyh which not only diffused the sunlight but also allowed it to spread evenly throughout the interior."

The Meshrabeyh was used to reduce the brightness from the sky, as mentioned above, and still provide ventilation. Another concept was that the rooms facing onto the shaded courtyards could avoid the brilliance of the sun's rays by use of colour and vegetation (Atkinson, 1952).

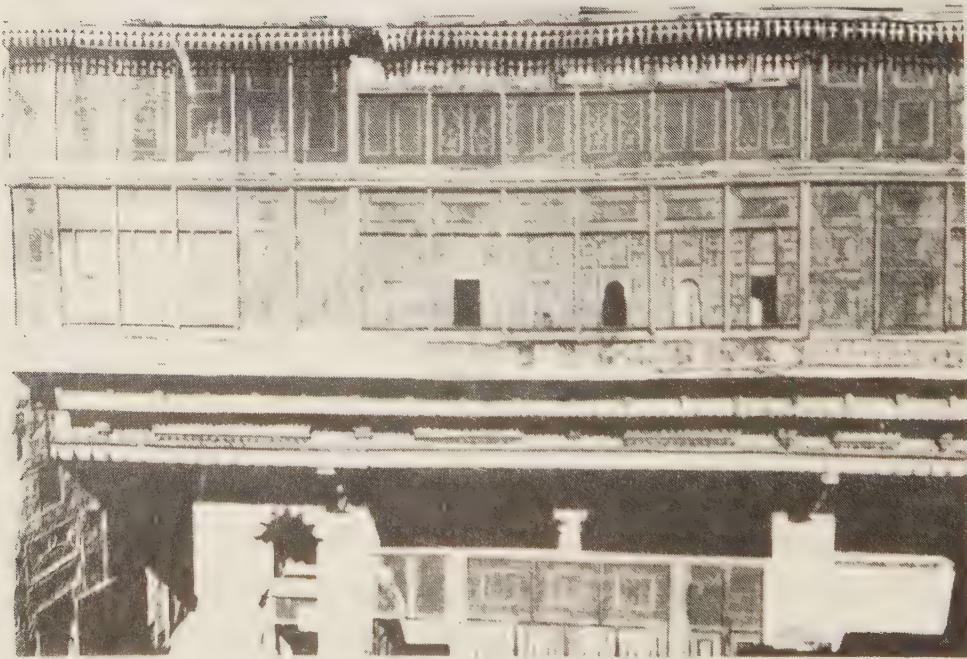


Figure 4.3.13 Usual large windows on the second floor with latticed wood. (Pauty, 1932).

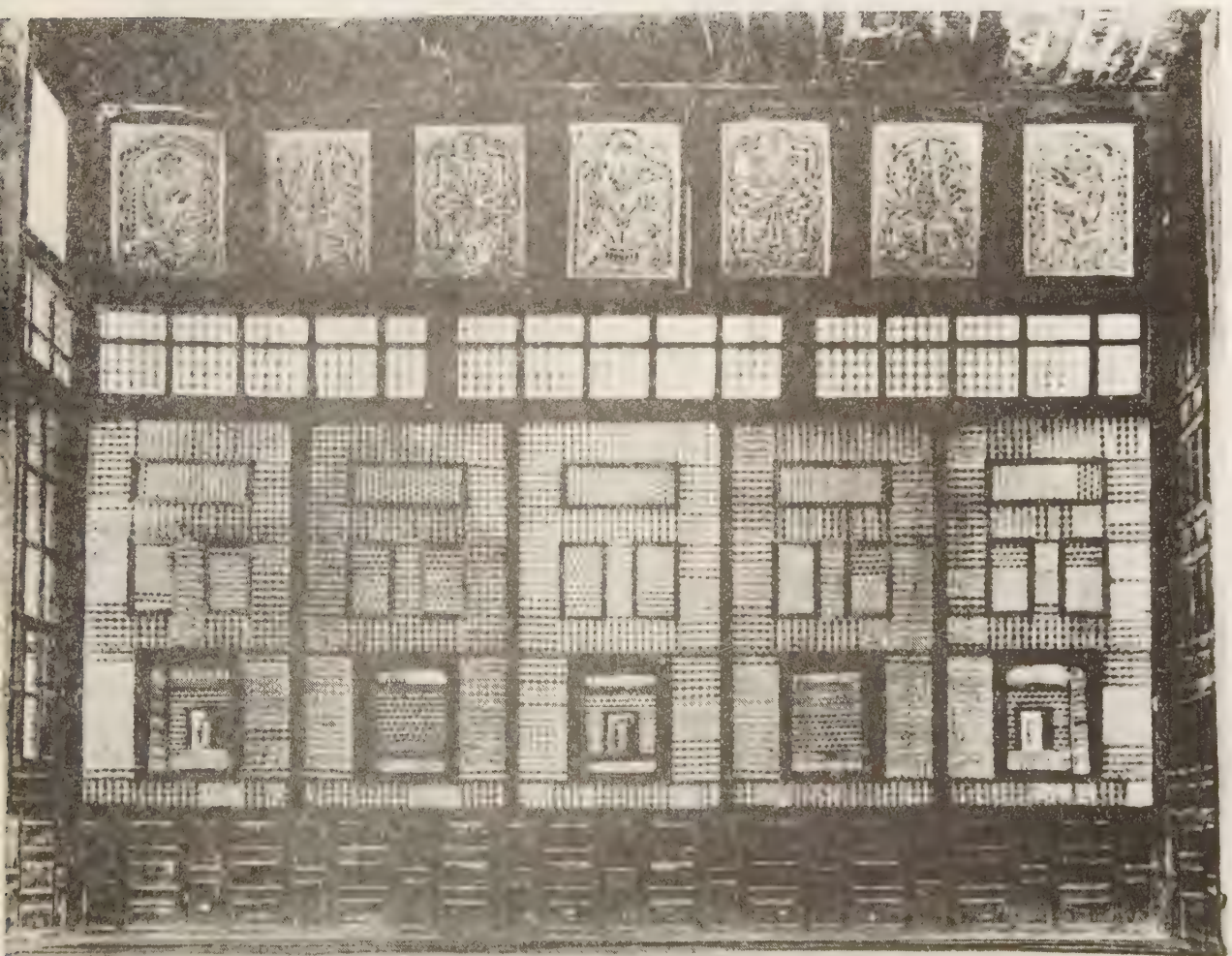
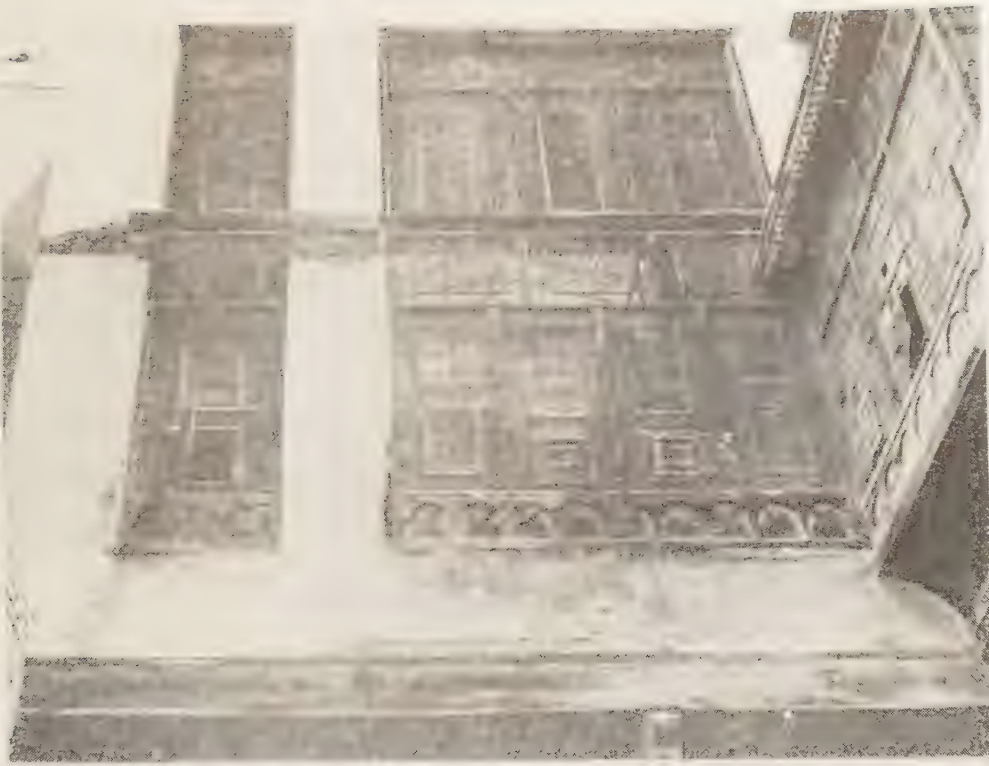


Figure 4.3.14 The window can stretch the width of the wall but be treated with lattice-wood to reduce the light and glare and at the same time allow air to enter. The Meshrabeyh can also screen the inmates of the house from the view of persons outside. (Revoult and Maury, 1975).

4.4 NATURAL VENTILATION AND COOLING SYSTEM

Ventilation is a vitally important factor for comfort in summertime. Wind direction in Egypt is constant from north-northwest and is relatively cool and special ventilating shafts have been provided to direct this breeze to the interior of the building. The ventilator used in the Islamic type of house is called "Malkaf", and consists of a sloping structure on the top of the house to deflect the breeze and direct it down into the rooms below (Lane, 1838).



Figure 4.4.1 Wind catch (malkaf) on top of the roof to deflect the air into the rooms below. (Revault and Maury, 1975).

a)

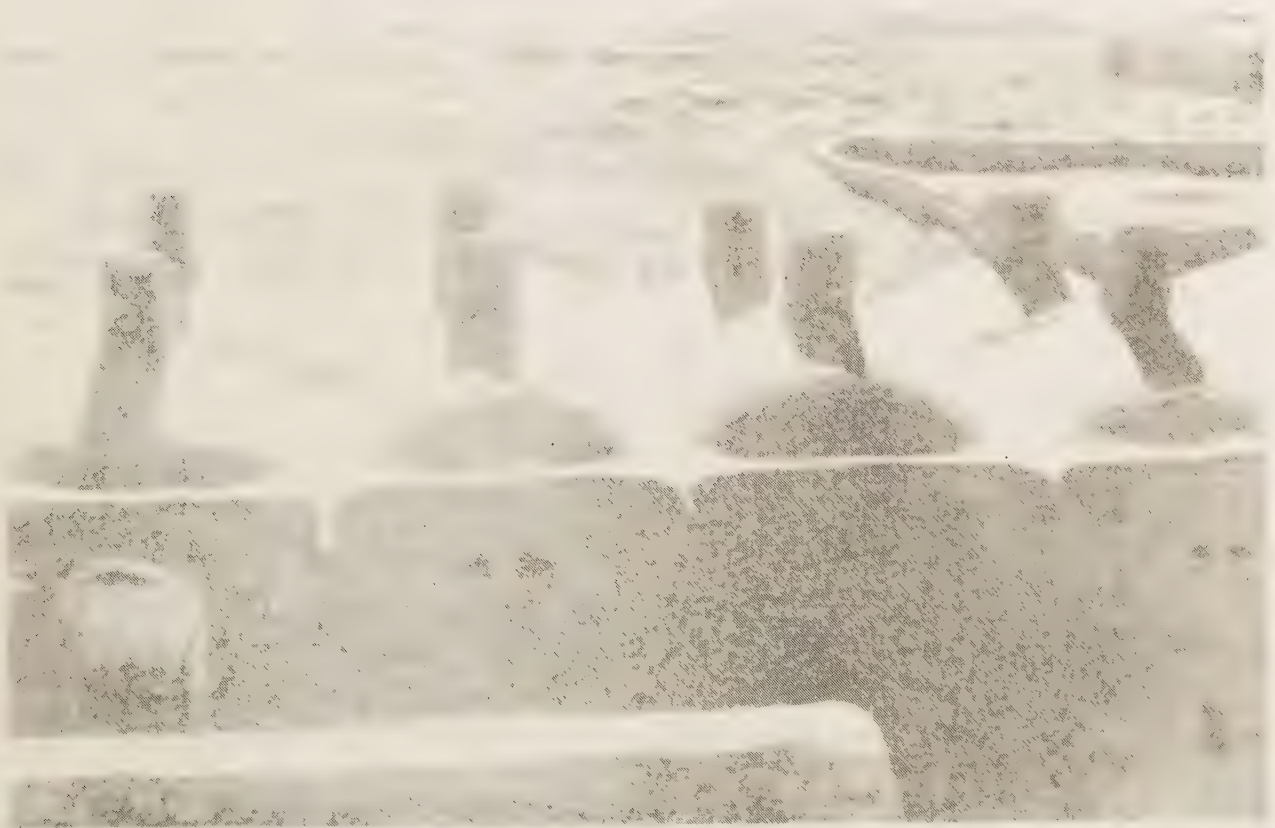


Figure 4.4.2 Wind catch on the top of flat roof constructed with sloping structure and plastered externally and internally. The slope is usually about 45 degrees and is directed to the prevailing wind. Wind catches on tops of dome roof, constructed of brick. The opening in wind catches is usually furnished with frames of glass which are closed in the winter. a (Revoult and Maury, 1975), b (Coon, 1952).

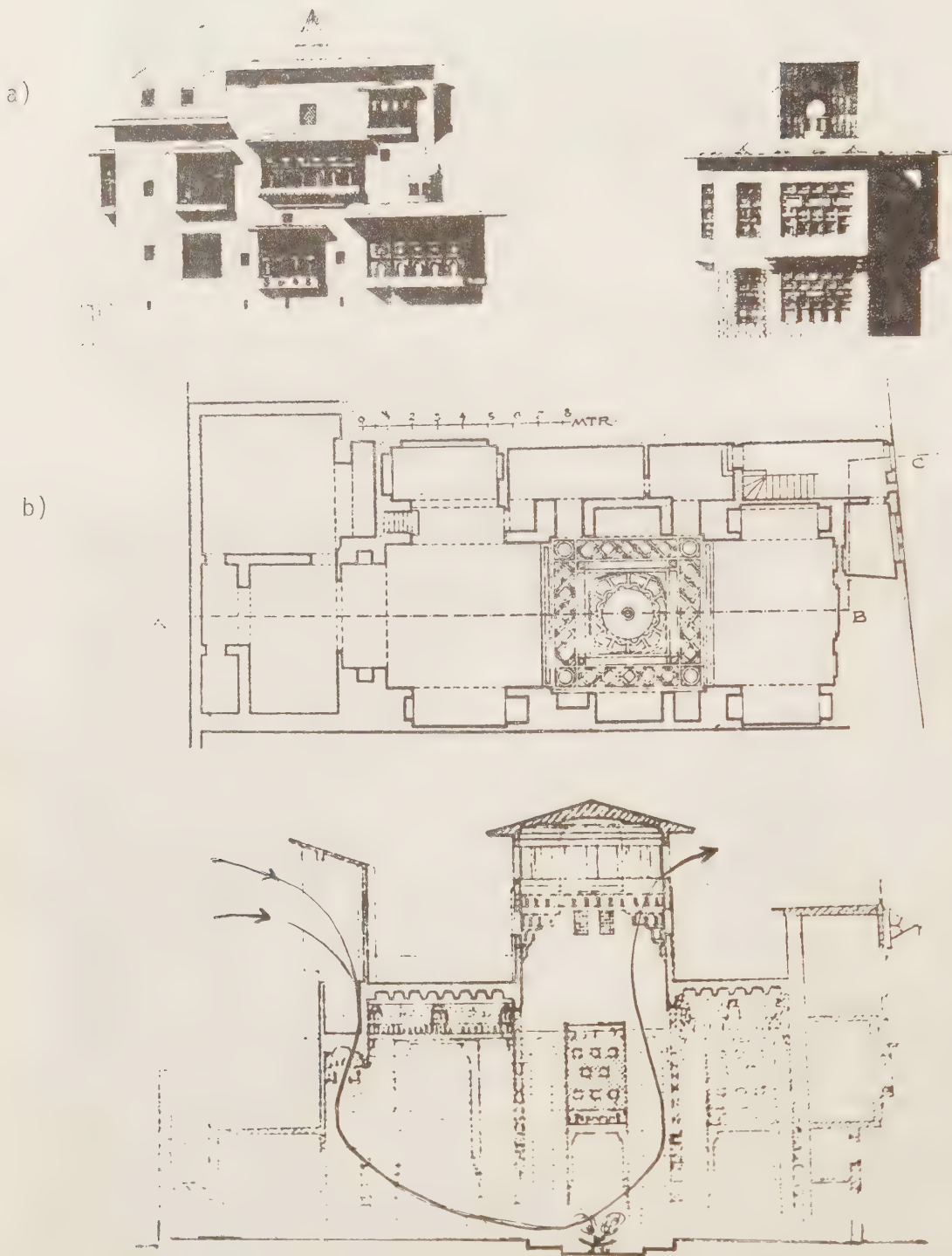


Figure 4.4.3

- a) shows the elevation of the house with wind catch on top of the roof. (France, 1809).
- b) shows plan and section of summer room. The external air deflected by the wind catch down to the room below passes over a fountain or pool of water in the middle of the summer room. Evaporation cools the air which can escape from an opening near the ceiling. (Fathy, 1973)

COURTYARD: The best use for external space is the courtyard which is found in most Islamic planning. A considerable part of the Arab's family life is spent in the courtyard. It is also an excellent thermal regulator in many ways. The high walls cut off the sun's rays and large areas of the inner surfaces of the house and the courtyard floor are shaded during the day. The wall of the courtyard also stops the entry of dust and sand into habitable rooms.

Windows near the ground that open into the courtyard can admit air freely as well as subdued lighting from the shaded courtyard.

The courtyard is usually planted. The evaporation from the leaves provides cooling of the ambient air. In addition to reducing the air temperature, the trees give occupants protection from the sun's rays. Deciduous trees with thermal seasonal foliage are especially suitable, providing shade in summer but permitting the sun in winter when it is welcome. In old traditional houses a fountain or pool of water is usually found in the courtyard.

Creswell (1959) has noted one house which was found in Fostat town. Figure 4.4.6 shows that on the side opposite the main living quarters is a room (g) about 3 m x 2.5 m which is flanked by shallow panels.

In this room there is a basin (k) which is directly connected to the main pool in the courtyard by means of a channel (m). Behind the basin is a recess and pipe (a2) which stands vertically in the wall behind it. The recess was intended to take a sloping marble slab with a ridged surface (perhaps a series of chevrons) down which the water from a tap (served by a2) would run in a thin film and cool the air by a slight evaporation, then run into (k) and finally by means of the channel (m) into the center of the courtyard (j). Such an arrangement is called a "Salsabil".

However, one can also find the same evaporation system described earlier in the main summer rooms which are called "mandarah". Count (1890), Crace (1870), and others have described the "Salsabil" in the house of the Mufti in Cairo, see Figure 4.4.7. To the left of the door 'A' is a recess in the wall from which refreshing water flows in a thin stream

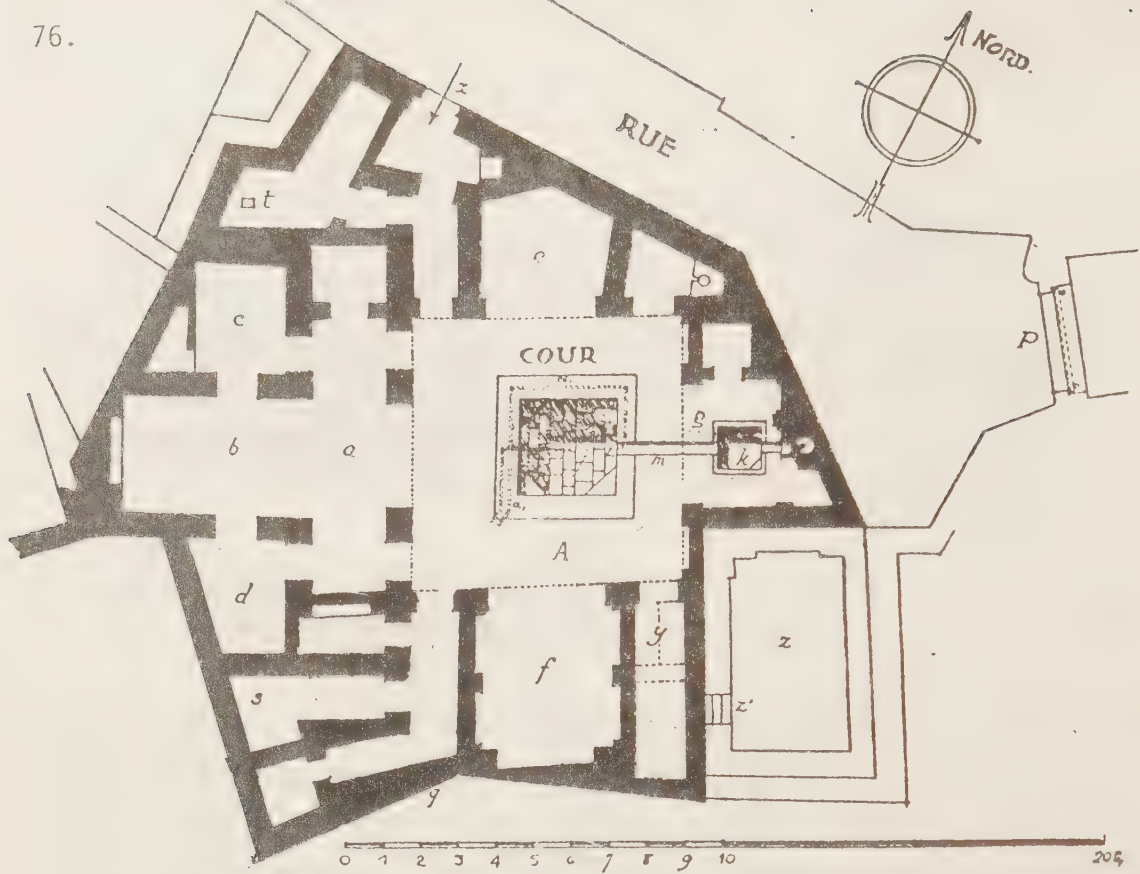
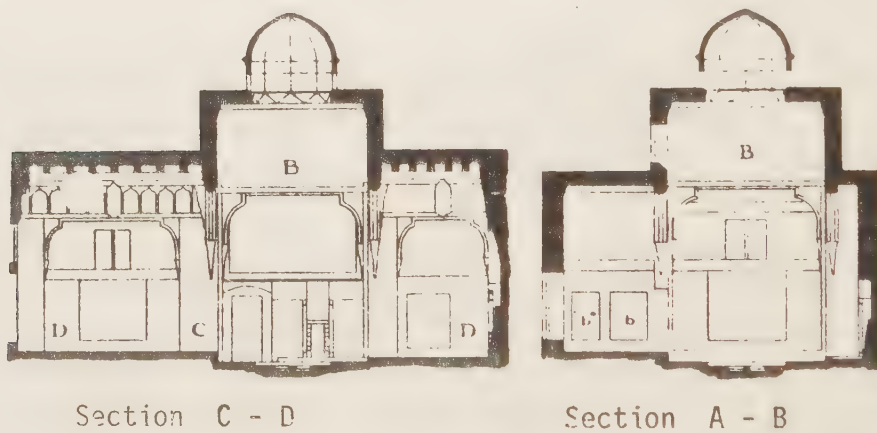


Figure 4.4.6 Plan of Fostat house with cooling system "Salsabil". (Creswell, 1959).



Section C - D

Section A - B

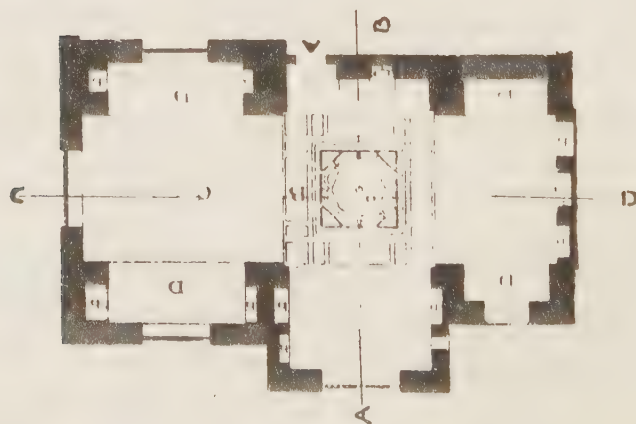
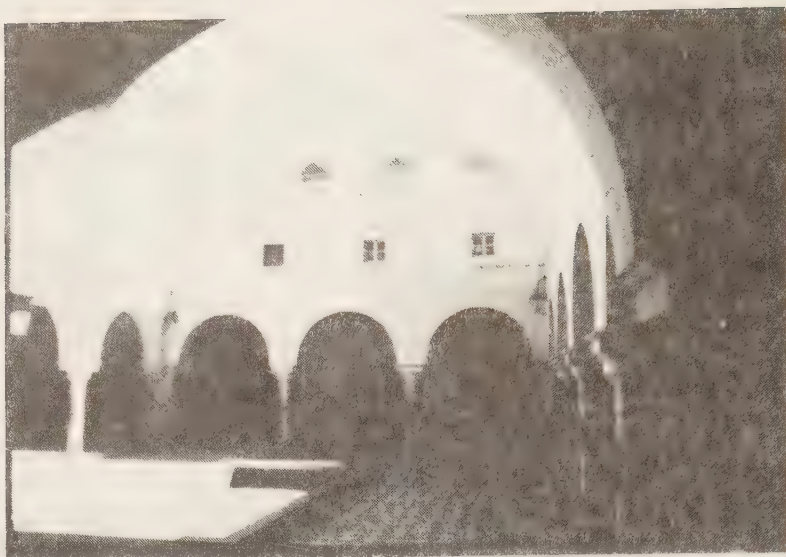


Figure 4.4.7 The cooling system "Salsabil" in the summer room. (Count, 1890).



Figure 4.4.4 The courtyard is usually planted and there is a fountain in the middle to cool the air before it enters the inside. (Lezine, 1972).



a)



b)

Figure 4.4.5 By means of a gallery around the courtyard of a suitable height or with suitable proportions between width, length and height of its walls, shade can be controlled in the summer and the sun's rays can penetrate indoors in winter time.

b (Revoult and Maury, 1975).

over ornamented and somewhat inclined marble slabs, and gathers in the floor in a marble channel to be conducted from there to a center basin with a fountain jet.

"MESHRABEYH": There are many traditional methods of evaporative cooling such as a blind which water is allowed to trickle over or is thrown on, a movable screen of woven straw or millet (Oakley, 1961).

In Islamic houses another method which is used for cooling is called "Meshrabeyh". This is a projection from the external window made of lattice-wood and used to screen the sun's rays and let the air pass to the interior.

This Meshrabeyh can project from the front or either side of a large window on the second floor. The projection allows exposure to a current of air. Inside the projection, a jar for cooling water is placed. From the jar pores a certain amount of water seeps through constantly to the external surface and evaporates in the air current passing over it. Consequently the remaining water is cooled and can be used for drinking. Hence the name "meshrabeyh", which means "a place for drink or for drinking".

In addition, the supply air temperature will be decreased and moistened by passing over the wet surface on its way to the indoor.

Figure 4.4.8

The meshrabeyh from the outside. It is open in all directions and projects to admit the air which passes over the external surface of a water jar. (Lezine, 1972).

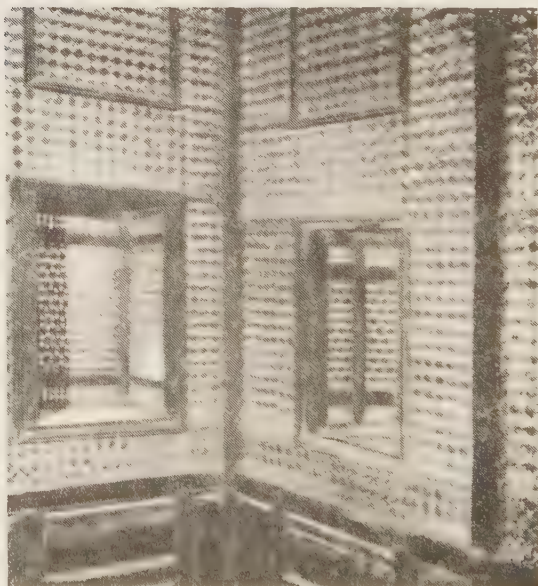
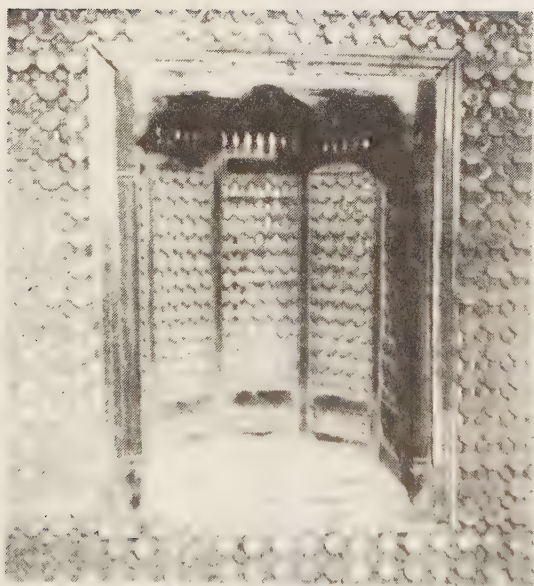
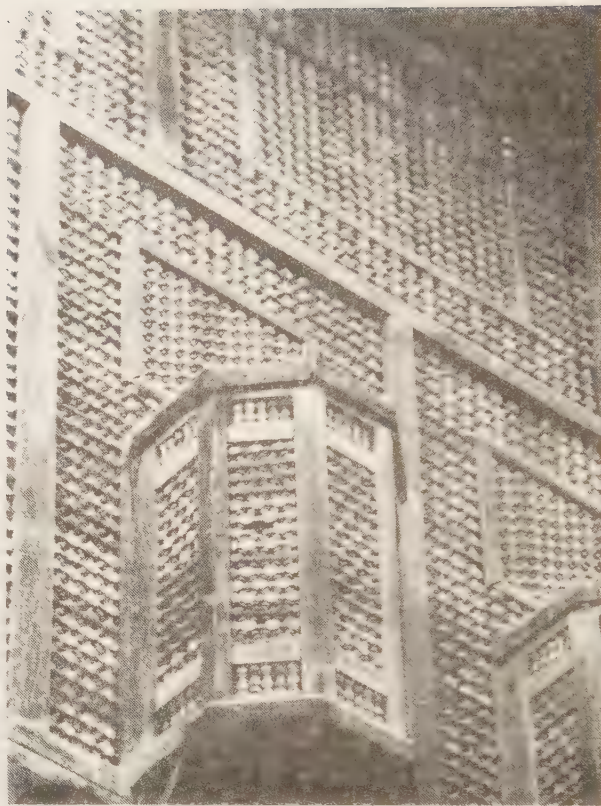


Figure 4.4.9 The meshrabeyh from the inside. Note the holes in the sill where the water jar is to be placed for cooling. (Revoult and Maury, 1975).

5 SENSITIVITY STUDY WITH RESPECT TO PASSIVE COOLING

5.1 SIMULATION MODEL FOR COMPUTER CALCULATIONS

5.1.1 Simulation of a building

The model of the building consists of a room in which all walls and roof are exposed to the outdoors. The room's dimensions are chosen to be 4.0 m wide, 5.0 m long and 2.8 m high (see Figure 5.1.1).

In order to study only the influence of building elements of the room on indoor temperature, the room is assumed without furniture, people or any supplementary heat. When examining the influence of the type of wall and its construction on indoor temperature, all other elements of the room, such as roof and floor constructions, window directions and size, colour of outside surfaces and of roof, are regarded as fixed. The room is assumed to be without ventilation unless mentioned. The wall will be studied with varying input (thickness, thermal capacity, resistance, etc.) and the output given as indoor air temperature, inside surface temperature and inner wall temperature, as well as external surface temperature and heat flow in internal and external surfaces.

The calculations are based upon the heat balance every hour, which means that temperature and heat flow are calculated every hour during very hot days in summer in Aswan (see Appendix 1). The day is repeated until a quasi-stationary solution is achieved.

The room has been represented by a thermal network which is shown in Figure 5.1.2. The network takes into account radiation transmitted through the window, reflexion and absorption in the panes and the absorption of transmitted radiation on the inside surfaces of the room, as well as long-wave radiation between the room surfaces.

The computer program which was used for calculation was the JULOTTA-program developed by Kurt Källblad (1972, 1979).

4

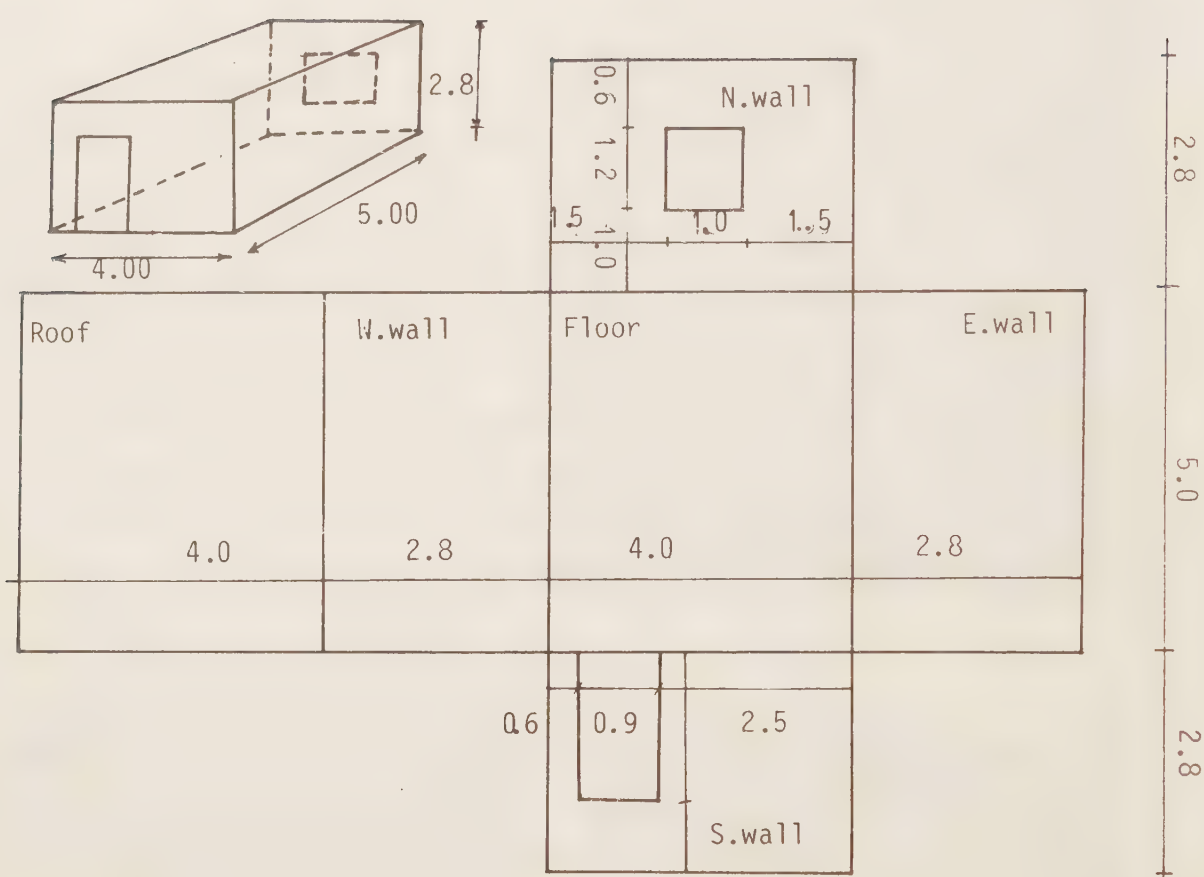


Figure 5.1.1 Room dimensions for model (1).

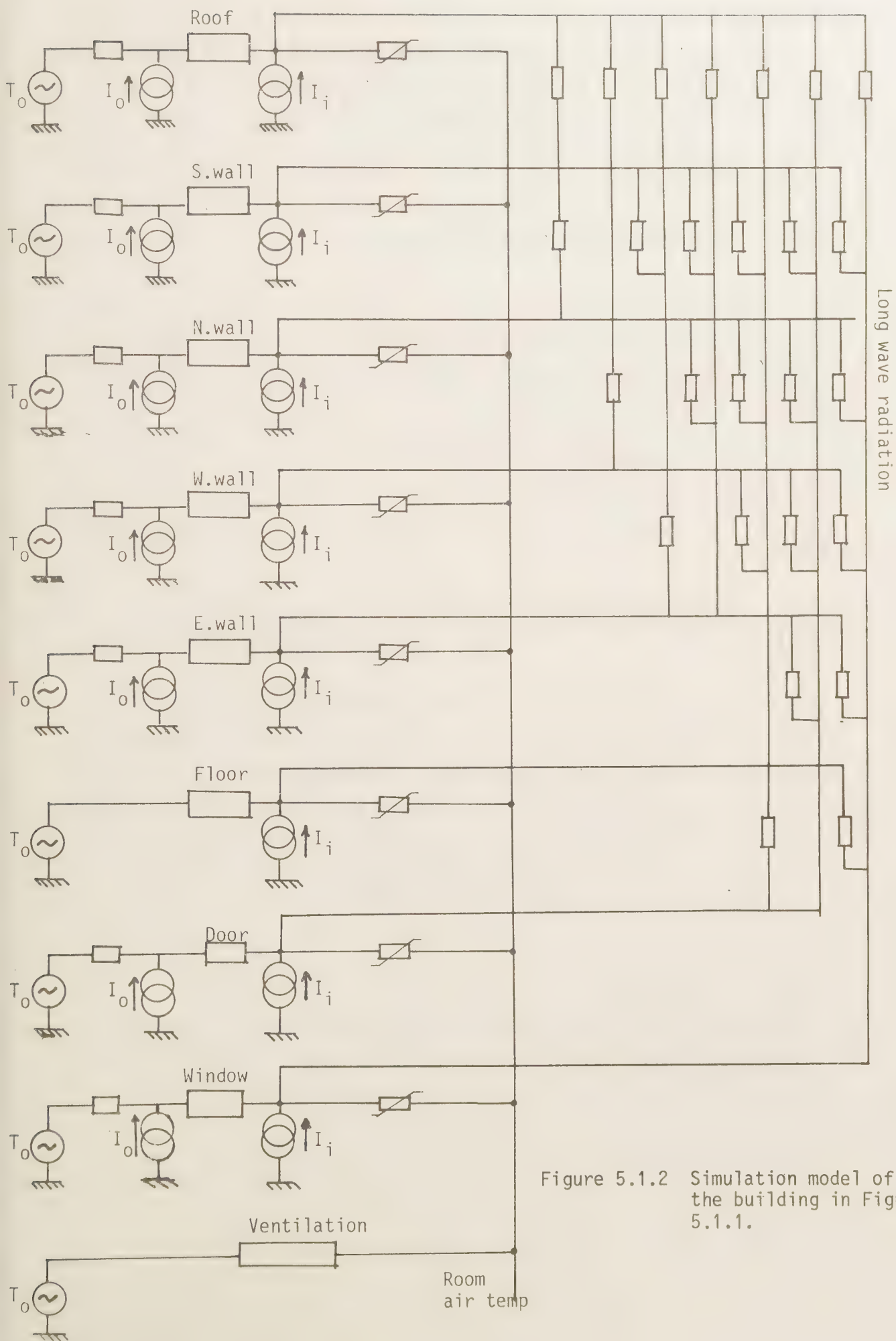


Figure 5.1.2 Simulation model of the building in Figure 5.1.1.

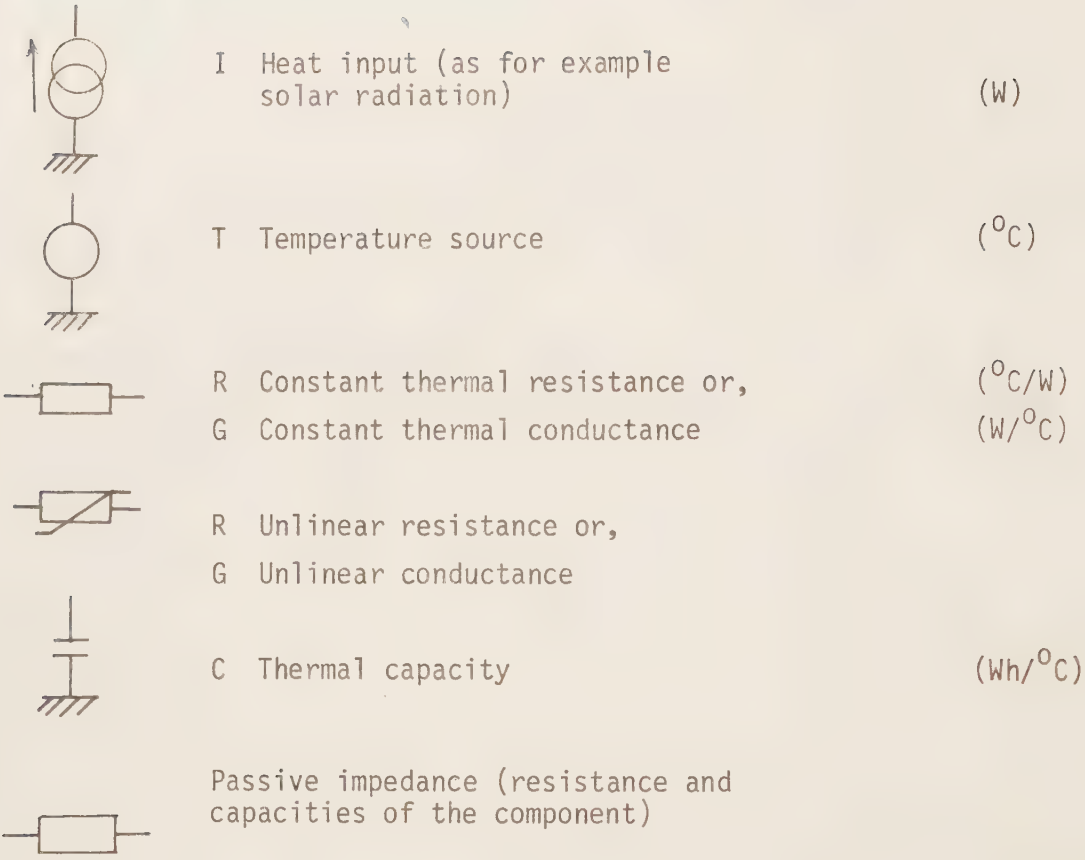


Figure 5.1.3 Symbols of the simulation model.

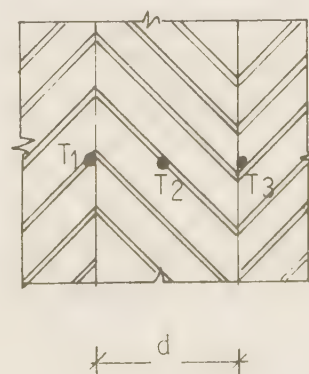
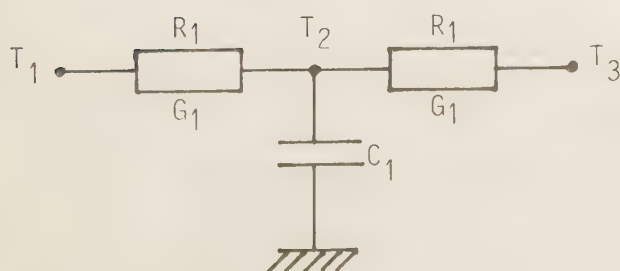
The roof is flat and is normally assumed to be a 200 mm concrete slab covered with 20 mm of asphalt, 50 mm sand, 20 mm mortar and 25 mm of cement tile, white in colour. The floor is assumed to be 150 mm ordinary concrete, covered with a layer of asphalt 20 mm thick, then ordinary concrete 100 mm thick, sand 50 mm, mortar 25 mm and finally cement tiles, 30 mm thick. The bottom surface of the floor is simulated with a thermal resistance $R=1.12 \text{ }^{\circ}\text{C}\cdot\text{m}^2/\text{W}$ to the outdoor air.

The walls are assumed to be constructed of red brick 108 mm thick and plastered on both sides with cement mortar 25 mm thick. The external surface is assumed to be grey in colour ($a=0.5$). The thermal network which is shown in section 5.1.3 is for the roof, floor, wall, and door and window. The window is assumed to be designed with a single pane of 3 mm glass, without frames, and with an external venetian blind facing north. The door has been assumed to be in a southerly direction and made of wood ($R=0.43 \text{ }^{\circ}\text{C}\cdot\text{m}^2/\text{W}$).

5.1.2 Simulation of heat flows

Simulation of a homogeneous layer

A homogeneous layer and part of a layer in a wall, roof or floor is simulated by two thermal resistances R_1 ($^{\circ}\text{C}/\text{W}$) or conductances G_1 ($\text{W}/^{\circ}\text{C}$) and one thermal capacity C_1 ($\text{Wh}/^{\circ}\text{C}$). The temperatures of the surfaces of each layer are denoted by T_1 and T_3 and the temperature in the middle, where the capacity is concentrated, is denoted T_2 .



The thermal resistance R_1 (conductance G_1), the thermal capacity C_1 and the heat flow P are calculated from

$$R_1 = \frac{d}{2\lambda A}$$

$$G_1 = \frac{2\lambda A}{d}$$

$$C_1 = c\rho dA$$

$$P = G_1(T_1 - T_2)$$

where R_1 = thermal resistance ($^{\circ}\text{C}/\text{W}$)

G_1 = thermal conductance ($\text{W}/^{\circ}\text{C}$)

d = thickness of the layer (m)

A = area of the component (m^2)

λ = thermal conductivity ($\text{W}/^{\circ}\text{C}, \text{m}$)

C = thermal capacity ($\text{Wh}/^{\circ}\text{C}$)

c = specific heat ($\text{Wh}/^{\circ}\text{C}, \text{kg}$)

ρ = density (kg/m^3)

P = heat flow (W)

T = temperature ($^{\circ}\text{C}$)

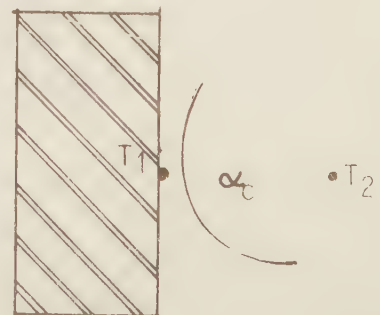
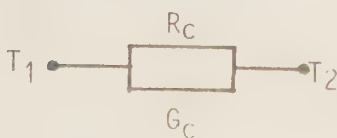
This way of calculating $R(G)$ and C is only valid for infinitely thin layers but has been used below also for relatively thick layers keeping in mind that this is an approximation. Such an approximation can be used in a parameter study where absolute values are not of the same interest as relative values. It has also been used by Adamson and Eftving (1979).

Convection at surfaces

Convection at a surface is simulated by a thermal resistance R_C ($^{\circ}\text{C}/\text{W}$) or conductance G_C ($\text{W}/^{\circ}\text{C}$) with

$$R_C = \frac{1}{\alpha_C \cdot A}$$

$$G_C = \alpha_C \cdot A$$



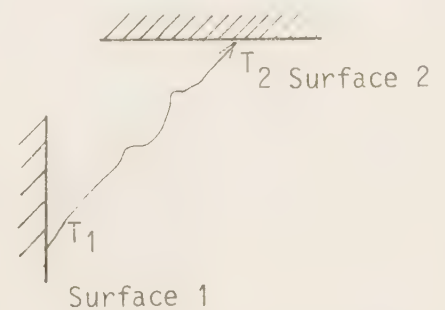
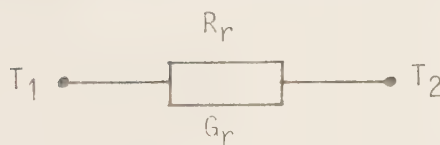
where α_c = heat transfer coefficient for convection ($W/^\circ C, m^2$)
 A = area of the surface (m^2)

The heat flow is

$$P_c = G_c(T_1 - T_2) \quad (W)$$

Long wave radiation between room surfaces

The long wave radiation between two room surfaces with different temperatures T_1 and T_2 (in $^\circ$ Kelvin) is simulated by a thermal resistance R_r ($^\circ C/W$) or conductance G_r ($W/^\circ C$).



The heat flow from surface 1 to surface 2 (black surfaces) is

$$P_r = A_1 \cdot \varphi_{1,2} \cdot \sigma (T_1^4 - T_2^4) \quad (W)$$

where

A_1 = area of surface 1 (m^2)

$\varphi_{1,2}$ = view factor (shape factor) for radiation from surface 1 to surface 2 (surface 2 viewed from surface 1)

σ = Stefan-Boltzmann's constant ($5.68 \cdot 10^{-8} W/K^4 m^2$)

T = temperature in $^\circ K$

If we write

$$P_r = G_r(T_1 - T_2)$$

$$G_r = A_1 \varphi_{1,2} \sigma \left(\frac{T_1^4 - T_2^4}{T_1 - T_2} \right)$$

If $T_1 \approx T_2 \approx T_m$ ($^{\circ}\text{K}$) we arrive in

$$G_r = 4 A_1 \varphi_{1,2} T_m^3 \sigma$$

The view factor $\varphi_{m,n}$ is normally computer-calculated or can be estimated by diagrams, see Adamson (1972).

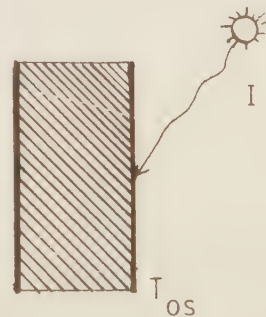
Normally all room surfaces emit nearly as much long wave radiation as a black surface. The emissivity for all non-metallic surfaces is between 0.92-0.95 and they can therefore be considered as black.

In the present simulation study the thermal conductances due to long wave radiation G_r have been assumed independent of T_m ($=308^{\circ}\text{K}$) and with $\xi=0.93$ we arrive in

$$G_r = 6.13 \cdot \varphi_{1,2} \cdot A_1 \quad (\text{W}/^{\circ}\text{C})$$

Absorbed solar radiation in outer surfaces

In outer surfaces solar and sky radiation is partly absorbed and heat is generated.



If the incident radiation is I (W/m^2), the absorbed heat in surface j is

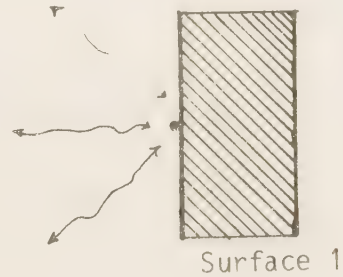
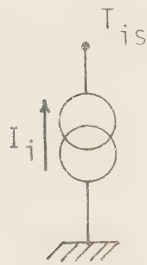
$$I_{0,j} = a_j \cdot A_j \cdot I \quad (\text{W})$$

where a_j = absorptivity of solar and sky radiation

A_j = area of the surface

Absorbed solar radiation in room surfaces

As in practically all computer programs, the JULOTTA-program assumes that the solar radiation is diffuse from the inner surface of the window glass to all the other room surfaces. The amount of heat absorbed in the surfaces depends on the reflection properties of all room surfaces including the window,



If I_0 (W/m^2) is the radiation from the surface 0 (glass), the absorbed heat in surface j is

$$I_{0,j} = A_j \cdot \Psi_{0,j} \cdot I_0 \quad (\text{W})$$

where $\Psi_{0,j}$ = distribution factor

The view factors ρ_{mn} and the distribution factors Ψ_{mn} for the room are shown in Appendix 1.3

Ventilation

Ventilation with fresh air of outdoor temperature gives the heat losses

$$P = c_p \cdot \rho \cdot V (T_i - T_o) \quad (\text{W})$$

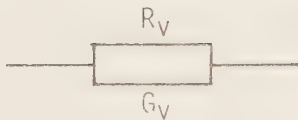
where c_p = specific heat of air (Wh/°C,kg)

ρ = density of air (kg/m³)

V = ventilation rate (m³/h)

T_i = indoor air temperature (°C)

T_o = outdoor air temperature (°C)



$$R_V = \frac{1}{c_p V}$$

$$G_V = c_p V$$

5.1.3 Thermal nets for components

Figure 5.1.4 shows the thermal nets for some components. The walls, roof and floor are divided into one or more layers, each represented with all its mass (thermal capacity) in the middle of the layer and with a conductance to the surfaces of the layer represented by half the layer thickness. This could be improved, at least for a single layer component, by choosing a reduced mass and a reduced distance from the center to the surface, see for example Adamson (1972).

A true physical layer-model has, however, been chosen as the simulation model because of its pedagogical value.

a) Wall

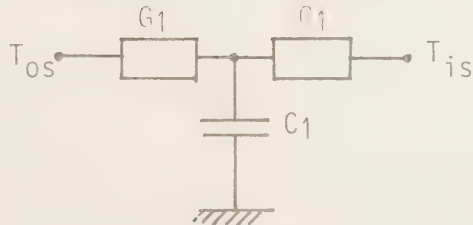


+108+

$$G_1 = 11.141 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$C_1 = 48.38 \cdot A \quad \text{Wh/}^{\circ}\text{C}$$

A=area of component (m^2)

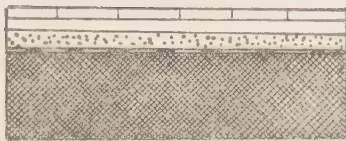


T_{os} =temperature at outside surface

T_{is} =temperature at inside surface

b) Roof

297



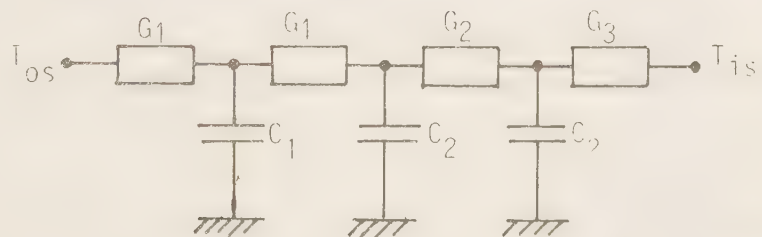
$$G_1 = 7.04 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_2 = 14.4 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_3 = 28.8 \cdot A \quad \text{W/}^{\circ}\text{C}$$

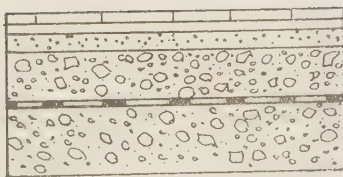
$$C_1 = 16.75 \cdot A \quad \text{Wh/}^{\circ}\text{C}$$

$$C_2 = 67.0 \cdot A \quad \text{Wh/}^{\circ}\text{C}$$



c) Floor

375



$$G_1 = 0.853 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_2 = 9.295 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_3 = 6.560 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_4 = 3.215 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_5 = 5.575 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$G_6 = 7.544 \cdot A \quad \text{W/}^{\circ}\text{C}$$

$$C_1 = 29.4 \cdot A \quad \text{Wh/}^{\circ}\text{C}$$

$$C_2 = 39.2 \cdot A \quad \text{Wh/}^{\circ}\text{C}$$

$$C_3 = 49.0 \cdot A \quad \text{Wh/}^{\circ}\text{C}$$

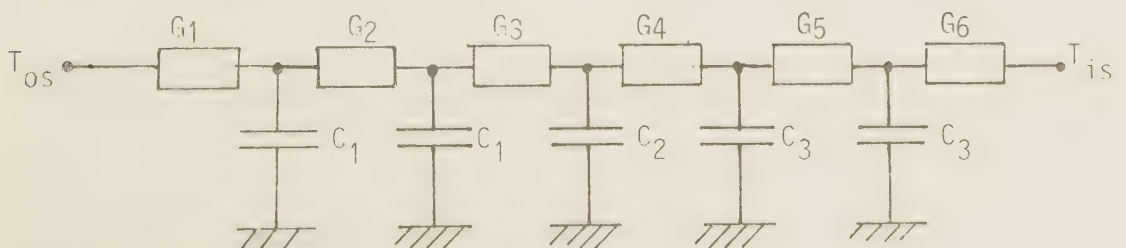
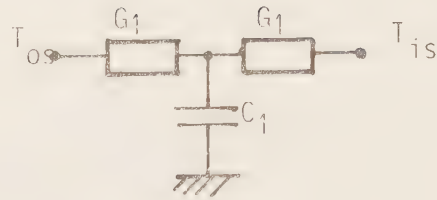


Figure 5.1.4a-c Thermal nets for wall, roof, floor.

d) Door



$$G_1 = 4.66 \cdot A \quad \text{W/}^\circ\text{C} \quad C_1 = 22.8 \cdot A \quad \text{Wh/}^\circ\text{C}$$



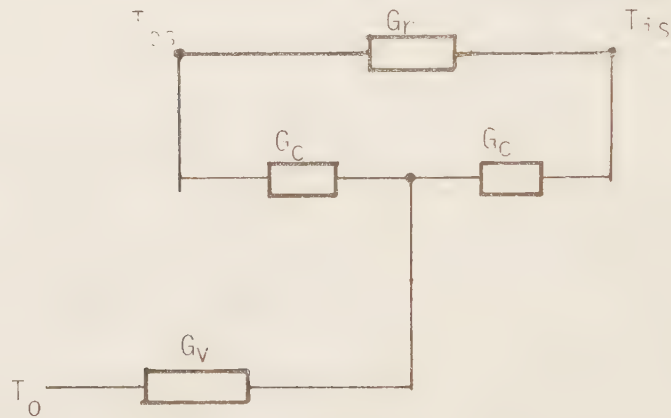
e) Window

Window area 1.2 m^2 facing north.

$$G_r = 6 \times 1.2 = 7.2 \text{ W/}^\circ\text{C}$$

$$G_c = 4 \times 1.2 = 4.8 \text{ W/}^\circ\text{C}$$

$$G_v = 0.35 \times n \times v = 0.35 \times 20 \times (1.2 \times 0.1) = 0.840 \text{ W/}^\circ\text{C}$$



- * shading devices reduce direct radiation according to their shape but diffuse radiation is assumed to be reduced by 20%.
- * venetian blinds are assumed to reflect 75% of direct radiation and absorb 25%
- * for diffuse radiation 35% will be reflected, 15% absorbed and 50% transmitted.

Figure 5.1.4 d-e Thermal nets for door and window.

5.2 INFLUENCE OF THE WALLS ON INDOOR TEMPERATURES

The external wall has several functions. One of them is to separate the indoor space from the external environment, or in other words to decrease the influence of the direct effects of outdoor climatic variables such as wind, rain, solar radiation, outdoor temperature etc.

If the wall is considered as several layers, the process of heat flow through a wall is as shown in Figure 5.2.1. When the outside surface temperature of the wall is higher than that of the next layer, there is a heat flow inwards. The heat flow into each layer will elevate its temperature and heat will be stored in the layer; excess heat will be transferred to the next layer. In this way each layer receives less heat than the preceding one. Consequently it has a smaller temperature rise than the layer externally adjacent to it.

After the external surface of the wall reaches its maximum temperature and starts to cool, the process is reversed. The heat which has been stored in the wall flows in two directions, inwards and outwards. As the outdoor air cools, a proportion of this stored heat flows outward.

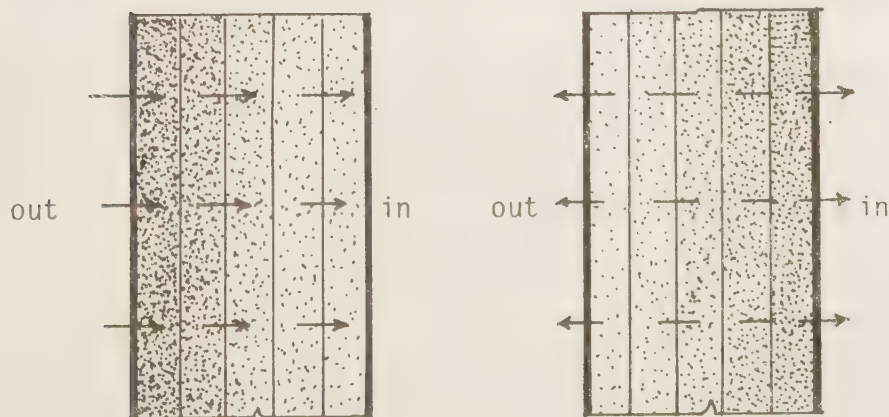


Figure 5.2.1 Stages of heat passage through layer of the wall.

In this way the wall under natural conditions undergoes wave-like cycles of heating and cooling during 24 hours, especially with high diurnal variations of the external surface temperature.

The ratio of internal to external surface temperatures of the wall depends on the thermophysical properties of its material, i.e. thermal conductivity, thermal capacity, density and surface characteristics with respect to radiation, absorptivity and reflectivity.

This study will show the influence of these factors on indoor temperature. By studying the materials commonly used for wall construction in Egypt, many questions will be answered as for example why the walls in traditional buildings are very thick. Suitable wall thickness and wall constructions to be used in extremely hot, arid regions with high diurnal variations of temperature will also be shown.

5.2.1 Influence of material and thickness of homogeneous walls

The simulation of the various design alternatives of homogeneous walls are shown in Table 5.2.1. It can be seen that even hollow brick has been simulated as a homogeneous material.

As a baseline the house is simulated with

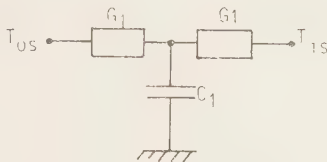
Roof (from above)	25 mm cement tiles
	20 mm mortar
	50 mm sand
	20 mm asphalt
	200 mm concrete
Window	single glazed (with external blind)
Floor (from above)	30 mm cement tiles
	25 mm mortar
	50 mm sand
	100 mm concrete
	20 mm asphalt

Table 5.2.1 Design alternative for homogeneous walls

1) Red brick 108 mm with plaster on both sides

$$G_1 = 11.14 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 48.38 \cdot A \text{ Wh/}^\circ\text{C}$$

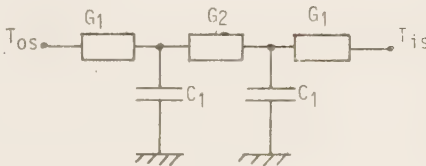


2) Double red brick 216 mm with plaster on both sides

$$G_1 = 11.14 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 48.38 \cdot A \text{ Wh/}^\circ\text{C}$$

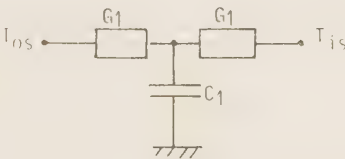
$$G_2 = 9.28 \cdot A \text{ W/}^\circ\text{C}$$



3) Limestone 100 mm with plaster on both sides

$$G_1 = 11.17 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 41.5 \cdot A \text{ Wh/}^\circ\text{C}$$

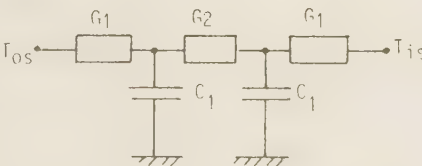


4) Limestone 200 mm with plaster on both sides

$$G_1 = 11.17 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 41.5 \cdot A \text{ Wh/}^\circ\text{C}$$

$$G_2 = 9.34 \cdot A \text{ W/}^\circ\text{C}$$



5) Limestone 400 mm with plaster on both sides

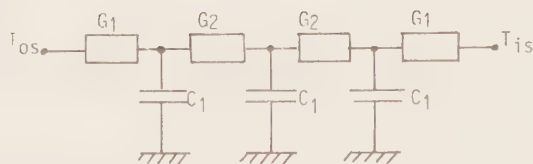
$$G_1 = 11.17 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 41.5 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 9.34 \cdot A \quad \text{W/}^\circ\text{C}$$



400

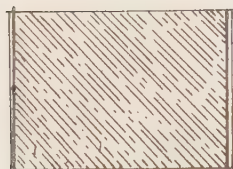


6) Limestone 600 mm with plaster on both sides

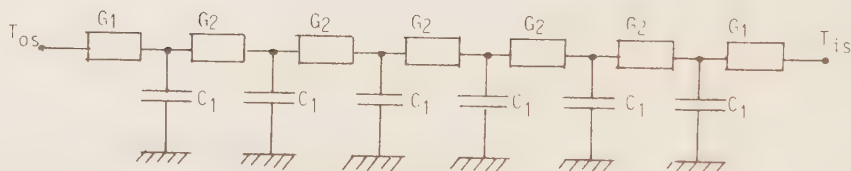
$$G_1 = 11.17 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 41.5 \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 9.34 \cdot A \quad \text{W/}^\circ\text{C}$$



600

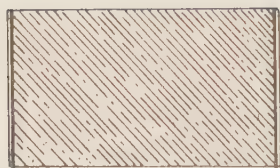


7) Limestone 800 mm with plaster on both sides

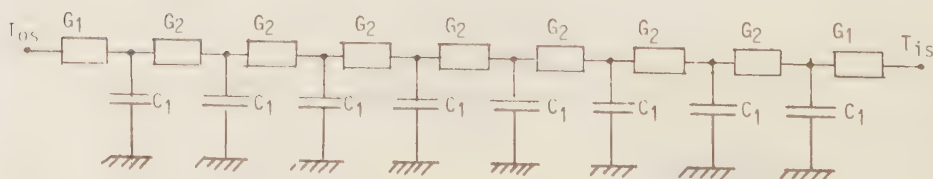
$$G_1 = 11.17 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 41.5 \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 9.34 \cdot A \quad \text{W/}^\circ\text{C}$$



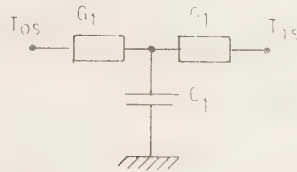
800



8) Hollow red brick 100 mm with plaster on both sides

$$G_1 = 7.19 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 30.2 \cdot A \text{ Wh/}^\circ\text{C}$$

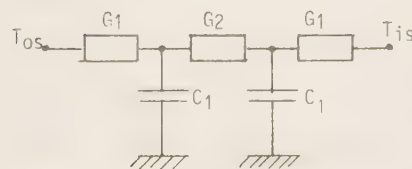


9) Double hollow red brick 200 mm with plaster on both sides

$$G_1 = 7.19 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 30.2 \cdot A \text{ Wh/}^\circ\text{C}$$

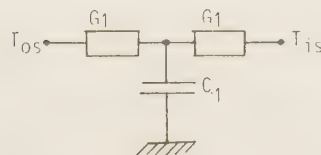
$$G_2 = 4.84 \cdot A \text{ W/}^\circ\text{C}$$



10) Concrete 100 mm with plaster on both sides

$$G_1 = 14.17 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 67 \cdot A \text{ Wh/}^\circ\text{C}$$

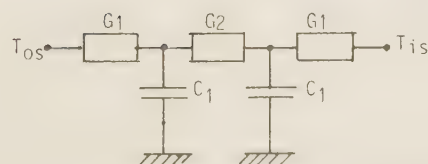


11) Concrete 200 mm with plaster on both sides

$$G_1 = 14.17 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 67 \cdot A \text{ Wh/}^\circ\text{C}$$

$$G_2 = 14.4 \cdot A \text{ W/}^\circ\text{C}$$



floor (cont'd)	150 mm concrete + thermal resistance to outdoor air $R = 1.12 \text{ } ^\circ\text{C}\cdot\text{m}^2/\text{W}$
Ventilation	0.25 air changes per hour during day and night
Absorptivity of outer surfaces	$a = 0.5$

A comparison between temperatures in thick and thin walls is shown in Figure 5.2.2. This shows the difference between a wall made of 100 mm limestone and another 600 mm thick, both facing east. When the outer surface reaches its maximum temperature at 1000 h (10 a m) and the outdoor temperature is $42.8 \text{ } ^\circ\text{C}$, the difference between the outer surface temperature of the walls 100 mm thick and 600 mm thick respectively will be insignificant, but the inside surface temperature of the 100 mm thick wall will be about $1.6 \text{ } ^\circ\text{C}$ lower than the outdoor temperature. For the 600 mm thick wall, the inside surface temperature will be $3.4 \text{ } ^\circ\text{C}$ lower than the outdoor temperature.

At 1400 h (2 p m) when the outdoor temperature is $46.8 \text{ } ^\circ\text{C}$, the inside surface temperature of the 100 mm thick wall will be $2 \text{ } ^\circ\text{C}$ lower than the outdoor temperature. For the 600 mm thick wall the difference will be $7.5 \text{ } ^\circ\text{C}$.

At 1900 h (7 p m), when the outdoor temperature is $35.9 \text{ } ^\circ\text{C}$, the inside surface temperature of the 100 mm thick wall will be $8.8 \text{ } ^\circ\text{C}$ above outdoor temperature and for the 600 mm thick wall $3.6 \text{ } ^\circ\text{C}$. At 2300 h (11 p m) when the outdoor temperature is $24.8 \text{ } ^\circ\text{C}$, the inside surface temperature will be 14.0 and $14.8 \text{ } ^\circ\text{C}$ above outdoor temperature respectively.

When the outer surface reaches its minimum temperature at 0300 h (3 a m) and the outdoor temperature is $22.1 \text{ } ^\circ\text{C}$, the inside surface temperature for the wall of 100 mm thickness reaches $11.0 \text{ } ^\circ\text{C}$ and for the wall of 600 mm thickness $17.5 \text{ } ^\circ\text{C}$ above outdoor temperature. At 0700 (7 a m) when the outdoor temperature is $32.6 \text{ } ^\circ\text{C}$, the indoor tempera-

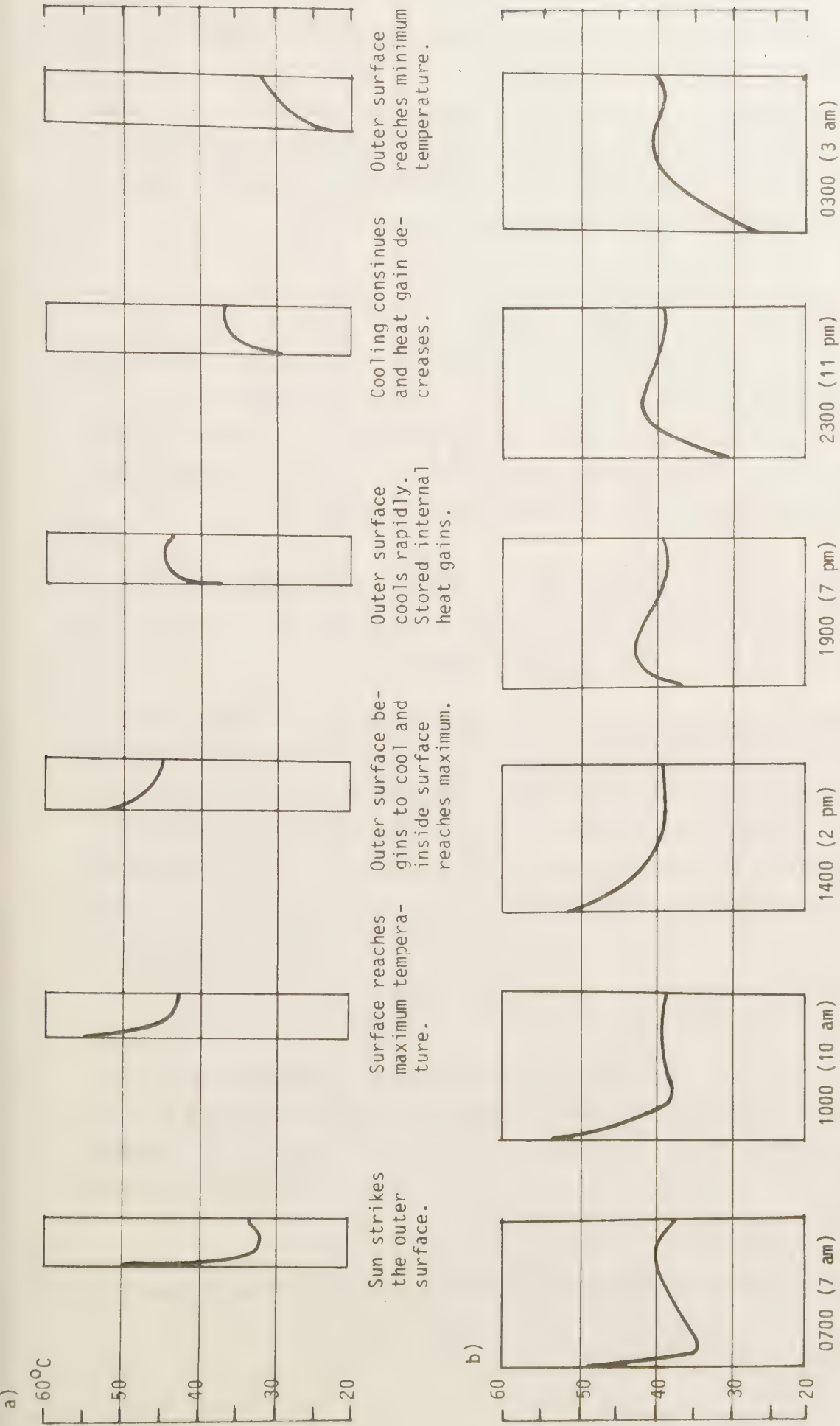


Figure 5.2.2 Response of east-facing limestone walls. Thickness a) 100 mm, b) 600 mm. Summer day.

tures will be 1.0 and 6.9 °C above outdoor temperature respectively.

This result means that in the case of the 100 mm thick wall the inside surface temperature fluctuates according to the outdoor temperature, but in the case of the 600 mm thick wall, the inside surface temperature is kept nearly constant during 24 hours.

The difference in thermal response between thick and thin walls is related to their volume heat capacity. A heavy wall will store more heat and less will be passed on to the indoor environment in day-time. At night, when outdoor air temperature is lower than indoor environment, the wall has a large amount of stored heat to dissipate to both the inside and the outside. The heat which is dissipated to the inside can heat the indoor air during the night in summer time.

Generally, in zones with large diurnal variation in outdoor air temperature, a lightweight structure stores little heat and the transfer of heat to the indoor space is almost instantaneous.

By comparing the maximum and the minimum temperatures of the outside surface, the inner wall layer and the inside surface, it can be seen (in Figures 5.2.3 and 5.2.4) that maximum outside surface temperature is about the same for thicknesses of 200, 400, 800 and 1000 mm but maximum inside surface temperatures are reduced and minimum temperature increases as the thickness of the wall increases. It shows also, that at a depth of 50 mm from the outside surface, the maximum inner wall temperature will be about 10.4 °C lower than maximum outdoor surface temperature for walls 200, 400, 800 and 1000 mm thick.

Figure 5.2.5 shows that when the limestone wall is 800 mm thick, the difference between maximum surface temperature and temperature at a point 50 mm deep from the outside surface is just 10.4 °C. At a depth of 150 mm it will be 17 °C and after 350 mm depth, the maximum temperature difference will not rise very much.

This means that increasing the wall thickness to more than 300 mm may be does not protect the interior from external heat.

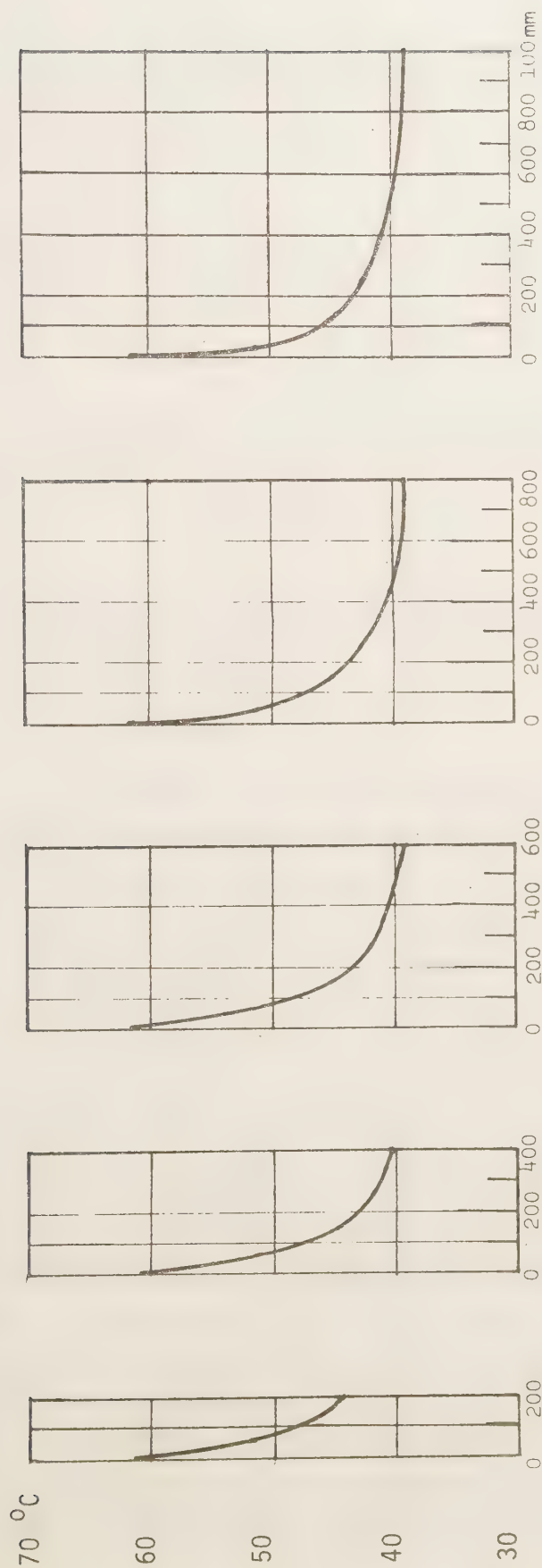


Figure 5.2.3 Influence of thickness of limestone walls facing west on the maximum temperature of the surfaces and in each layer of the wall (envelope).

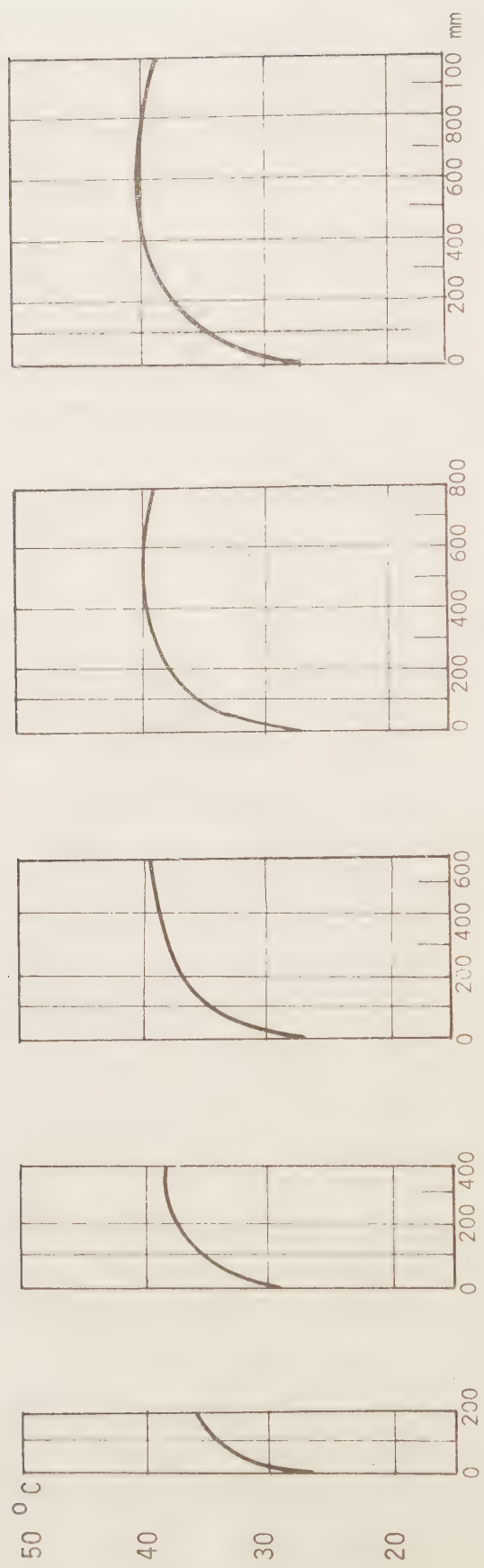


Figure 5.2.4 Influence of thickness of limestone walls facing west on minimum temperature of the surface and in each layer of the wall (envelope).

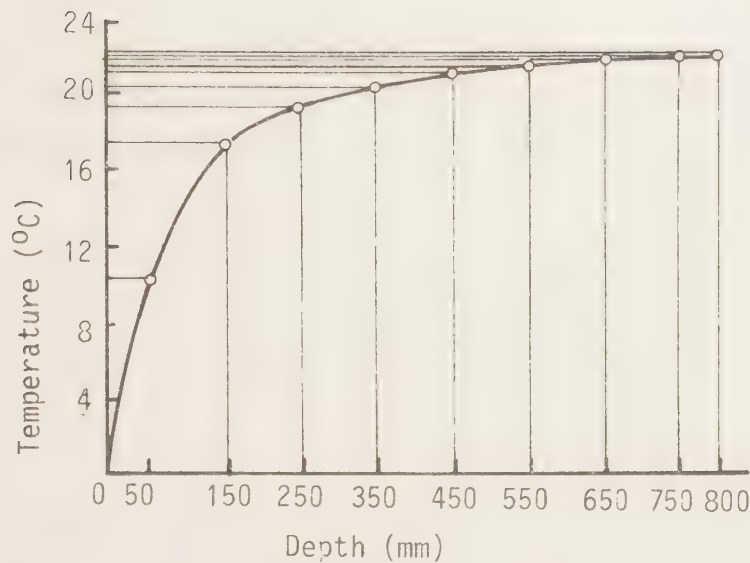


Figure 5.2.5 Temperature differences between maximum outdoor surface temperature and maximum temperature at a point x mm from the outdoor surface.

Thermal capacity and thermal resistance of the wall regulate indoor thermal conditions. The following will compare two identical rooms with different wall thicknesses in two cases: 1. the walls have different thickness and thermal resistance but are equal in thermal capacity and 2. the walls have different thermal capacity and thermal resistance but are equal in thickness.

Figure 5.2.6 compares room air temperature for two different walls, the first made of 200 mm hollow brick and the other made of 100 mm concrete. The ratio of the thermal resistance is about 3:1 and the heat capacity is about the same. It can be seen that the hollow brick wall reduces the maximum room air temperature by about 5.4°C from the maximum outdoor air temperature, but the concrete wall reduces the temperature by 2.8°C . Minimum room air temperature will be 15.3°C and 12.6°C above minimum outdoor temperature respectively. This means that the daily mean of the room air temperature will be about the same for both cases, but the daily swing in room air temperature will be lower for a room with hollow brick walls (high thermal resistance) than for

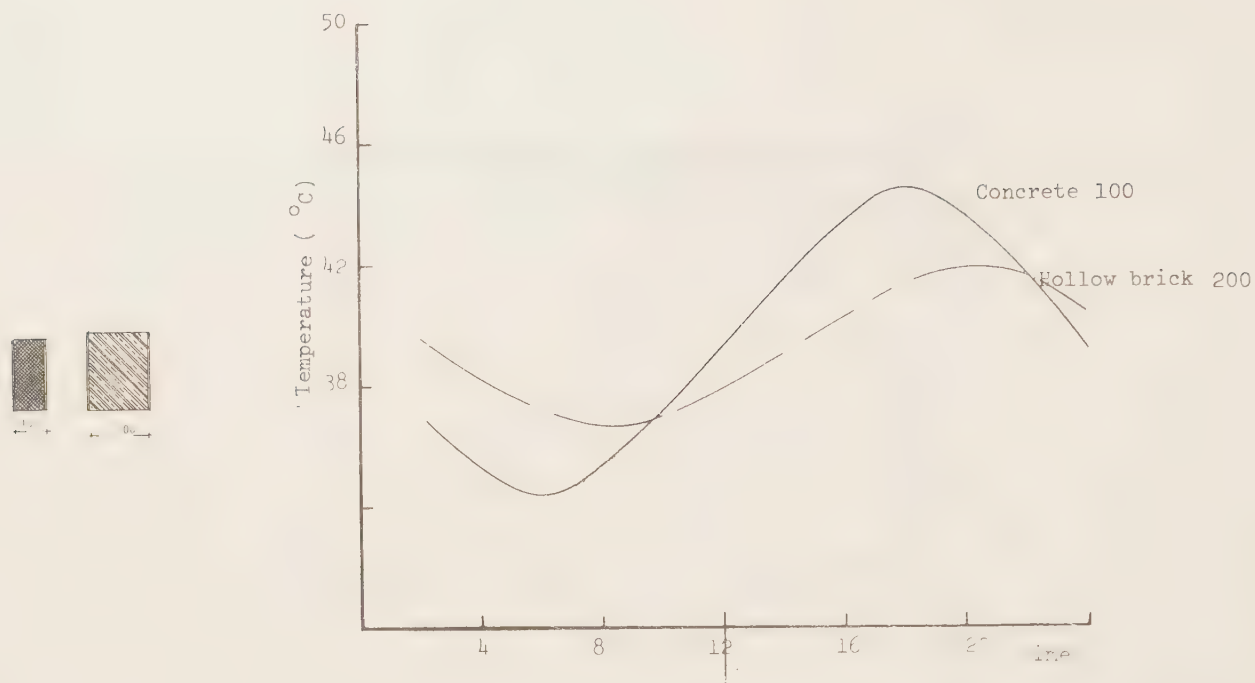


Figure 5.2.6 Influence of thermal resistance of wall on room air temperature.

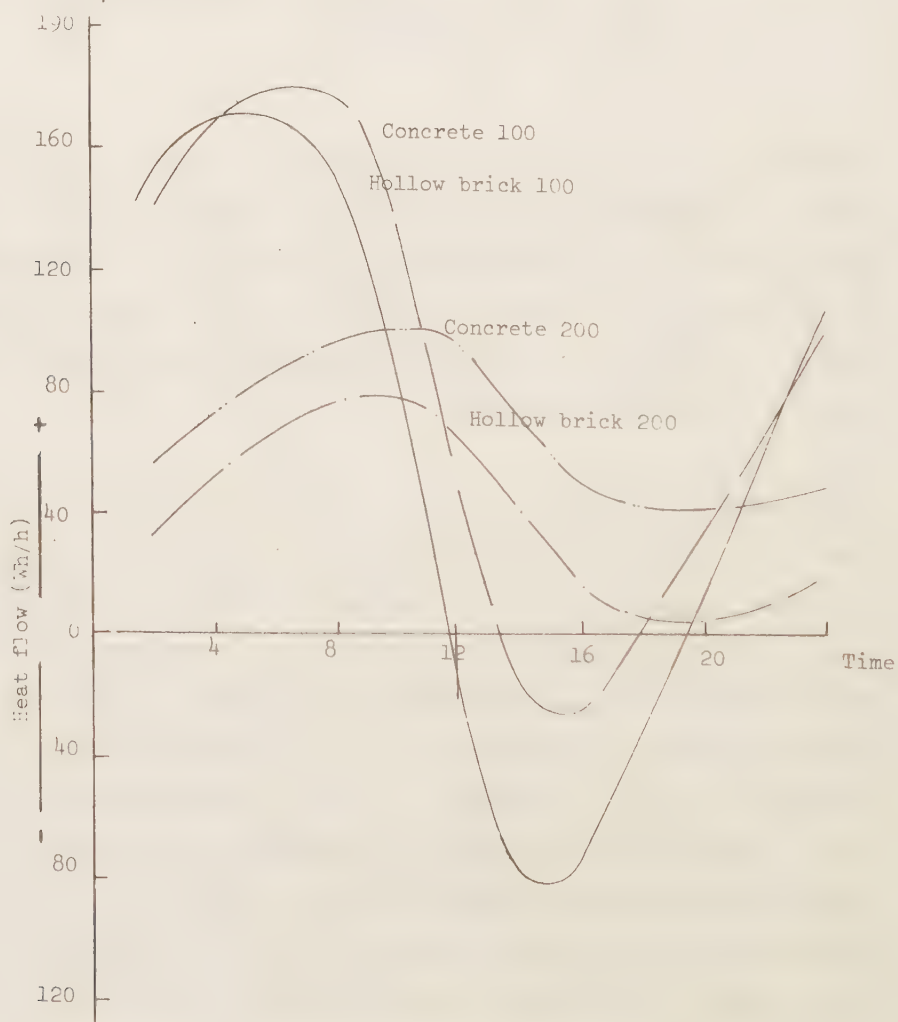


Figure 5.2.7 Heat flow at internal surfaces of walls facing south and made of 100, 200 mm hollow brick and ordinary concrete.

a room with concrete walls (low thermal resistance)..

From Figure 5.2.7 it can also be seen that 200 mm wall facing south does not emit heat to the interior, but the wall made of 100 mm hollow brick emits heat to the indoor from about 1200 h to 2000 h.

When the walls have the same thickness, the indoor temperature will depend on the wall materials. Table 5.2.2 shows a comparison between a wall made of concrete 100 mm thick (high thermal capacity and low thermal resistance) and another made of hollow brick 100 mm thick (high thermal resistance and low thermal capacity) both facing west. The table shows that the daily mean room air temperatures are about the same but the daily swing of room air temperature is lower for the case with concrete walls than for the case with hollow brick walls of equal thickness.

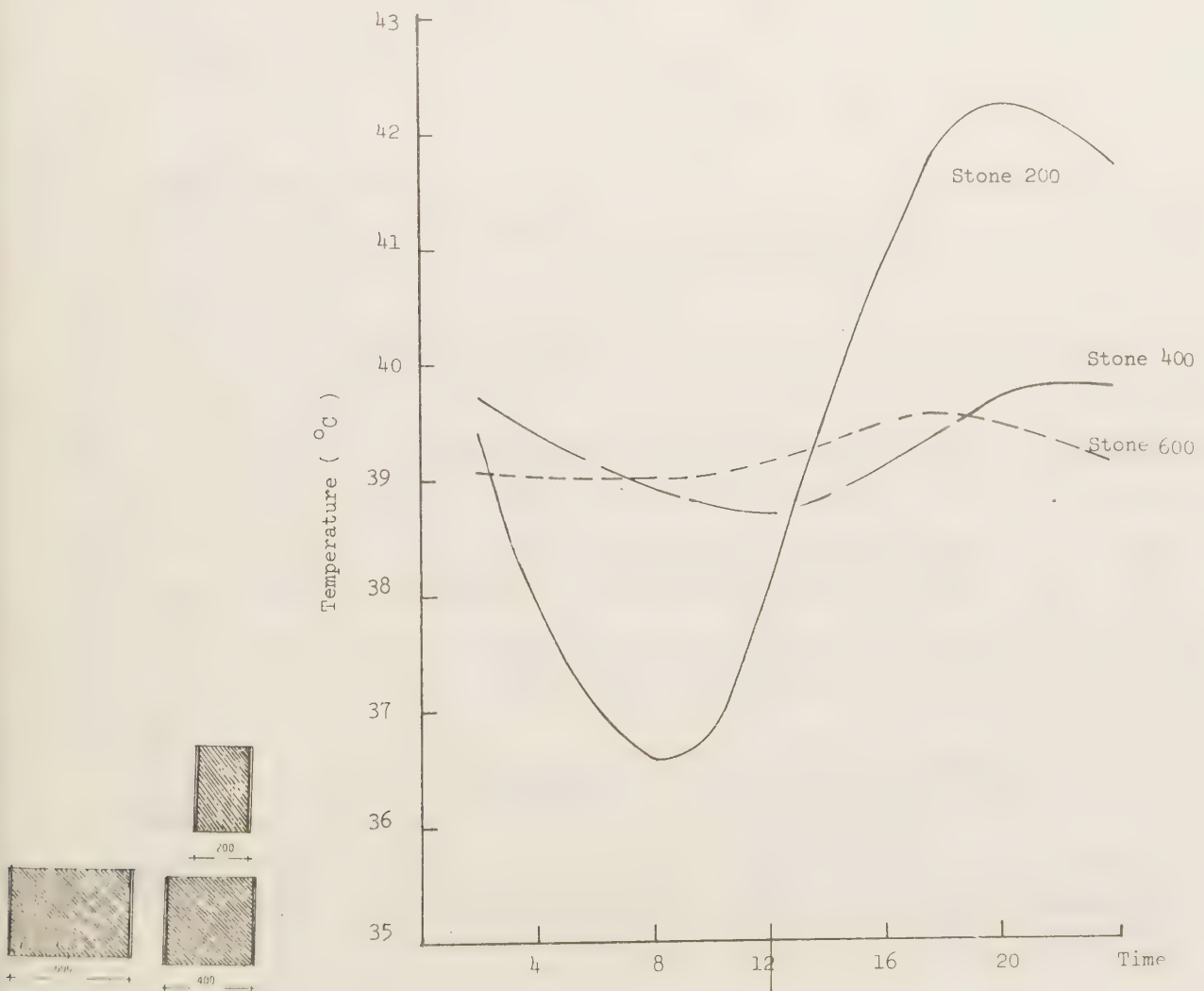


Figure 5.2.8 Influence of thickness of wall on room air temperature. Wall made of 200, 400 and 600 mm limestone.

It can also be seen that a wall with high thermal resistance increases external surface temperature. When the wall is made of hollow brick, the maximum external surface temperature will be 17°C above outdoor temperature, but when the wall is made of concrete (lower thermal resistance) maximum external surface temperature will be not more than 12°C above maximum outdoor temperature.

Figure 5.2.8 shows a comparison between room air temperature for rooms with different thicknesses of limestone wall. It can be seen that maximum room air temperature increases as thickness of the wall decreases and minimum room air temperature will increase as wall thickness increases. It is obvious that the daily mean of room air temperature will decrease only slightly by increasing thickness of the wall, but the daily swing of room air temperature will decrease considerably when the thickness is increased. In general, when the wall is 600 mm thick, there is an insignificant change in room air temperature during 24 hours, but with a thin wall, 200 mm thick, room air temperature fluctuates according to the outdoor temperature.

Table 5.2.3 shows heat flow to internal surfaces of a wall facing west. It can be seen that when the wall has the lowest thermal capacity (100 mm thick), the wall emits heat to the indoor space from 1300 h (1 p.m.) until 2300 h (11 p.m.), while the wall with high thermal capacity (600 mm thick) emits heat from about 2400 h (midnight) to 1500 h (3 p.m.), but in a lower degree than the thinner wall. However, a wall of heavy construction will heat the interior when the occupants want to sleep. Mayhew and Szokolay (1973) mention that it often happens that people in hot, dry climates sleep on the roof at least the first half of the night. After midnight they may go indoors, as the outdoor temperature has by then dropped to cool discomfort and indoors it may have cooled enough to be just comfortable.

In fact, in traditional buildings in a hot climate the ground floor is built with very thick walls but the reason is not only to protect the occupants from the external heat in summer. Mainly walls are built very thick because of weight-bearing and because the walls are constructed with natural stones which give thick walls.

Table 5.2.2

Influence of heat capacity and resistance of walls made of hollow brick and concrete 100 mm thick on external and indoor temperature.

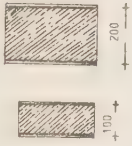


Time of day	Temperature °C					
	Room air			Inside surf. External surf.		
(h)	Con.	Hol.	Con.	Hol.	Con.	Hol.
01.00	37.9	37.0	38.1	36.4	29.5	26.0
02.00	36.9	35.9	36.6	35.0	28.4	25.2
03.00	35.9	35.1	35.3	33.9	28.0	25.1
04.00	35.1	34.4	34.2	33.0	28.2	25.8
05.00	34.5	33.9	33.4	32.5	29.0	27.2
06.00	34.1	33.8	33.0	32.3	31.1	30.2
07.00	34.6	34.4	33.1	33.0	33.7	33.7
08.00	35.2	35.6	33.8	34.1	36.5	37.4
09.00	36.3	36.9	34.8	35.6	39.3	41.0
10.00	37.5	38.2	36.0	37.2	41.9	44.2
11.00	38.6	39.4	37.4	38.8	44.2	46.8
12.00	39.6	40.3	38.8	40.3	46.5	49.5
13.00	40.4	41.1	40.2	41.7	51.4	55.4
14.00	41.3	42.1	42.0	43.4	55.5	60.3
15.00	42.3	43.0	43.9	45.2	58.5	63.6
16.00	43.2	43.8	45.8	46.8	59.8	64.5
17.00	43.9	44.4	47.3	48.0	58.3	61.9
18.00	44.3	44.7	48.2	48.4	52.4	53.7
19.00	44.2	44.3	47.9	47.6	42.9	41.1
20.00	43.6	43.3	46.4	45.5	40.2	37.7
21.00	42.7	42.1	44.7	43.4	37.5	34.6
22.00	41.5	40.6	43.1	41.5	35.1	31.8
23.00	40.3	39.3	41.4	39.6	32.9	29.4
24.00	39.1	38.1	39.7	37.9	31.0	27.4

Con. = Concrete, Hol. = Hollow brick

Table 5.2.3

Influence of thickness of wall made of limestone facing west on heat flow at internal surface.



Time of day	Heat flow (Wh/h)				
	100 mm	200 mm	400 mm	600 mm	
01.00	132.	-105.	-74.3	-19.4	
02.00	190.	-65.5	-82.6	-28.7	
03.00	233.	-28.4	-87.3	-37.5	
04.00	261.	5.3	-88.5	-45.2	
05.00	273.	33.6	-87.3	-51.5	
06.00	267.	59.0	-81.3	-55.0	
07.00	278.	78.4	-72.2	-56.6	
08.00	267.	96.9	-63.1	-57.8	
09.00	232.	111.	-51.7	-56.3	
10.00	174.	119.	-37.8	-52.3	
11.00	96.	117.	-24.2	-46.0	
12.00	13.7	105.	-9.6	-37.7	
13.00	-73.3	85.7	4.2	-28.1	
14.00	-210.	57.2	16.5	-17.3	
15.00	-369.	13.2	26.3	-8.0	
16.00	-523.	-44.7	32.8	0.2	
17.00	-640.	-115.	34.5	6.5	
18.00	-689.	-186.	31.5	10.8	
19.00	-616.	-248.	23.1	12.7	
20.00	-410.	-275.	9.8	12.7	
21.00	-250.	-258.	-8.0	10.1	
22.00	-126.	-225.	-28.2	5.1	
23.00	-23.4	-186.	-46.7	-1.7	
24.00	61.6	-145.	-62.2	-10.1	

Turning the building to different orientation

Orientation of the building is subject to many considerations such as view, topography of the site, etc. The orientation affects indoor temperature in two respects, through the direction of prevailing winds for cooling ventilation and through the incidence of solar radiation.

The following passage will deal with the second factor, the incidence of solar radiation. The orientation of a building affects the quantities of solar radiation incident on different surfaces at different times of the day. Each surface must be separately considered to achieve the most effective solar control. The problem is not only to protect the surfaces of the building against the maximum solar radiation in summer, but to allow it to strike the exterior wall for heating in the cool season.

To study the influence of orientation of a building on indoor temperature a model 4.0 m wide and 10.0 m long (Figure 5.2.10) is considered. The model has the double length of model (1) in Figure 5.1.1 in order to increase the influence of walls on the room air temperature - the same model is also used in section 5.5.

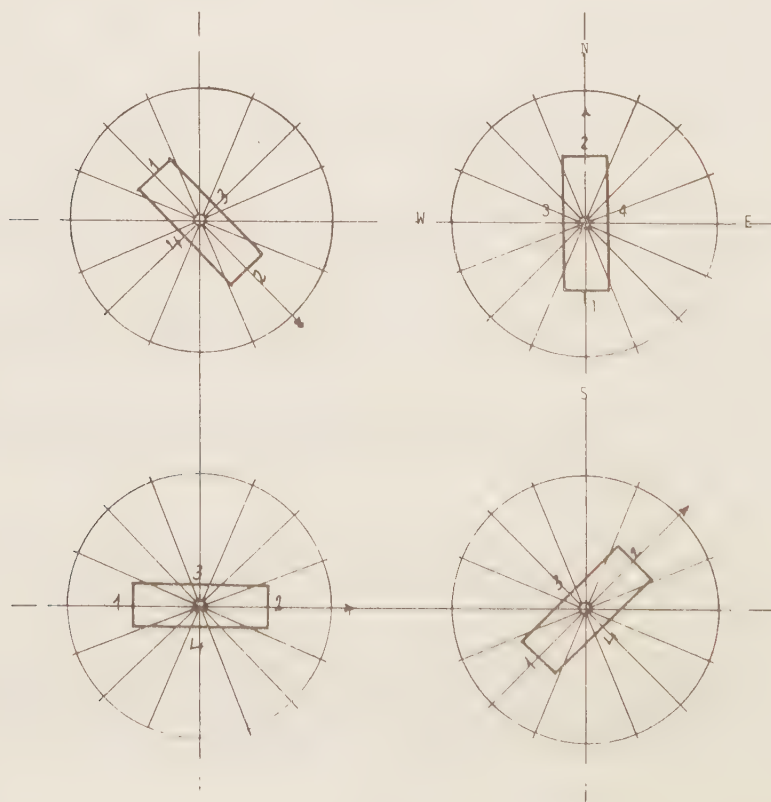


Figure 5.2.9 Orientation of model (2).

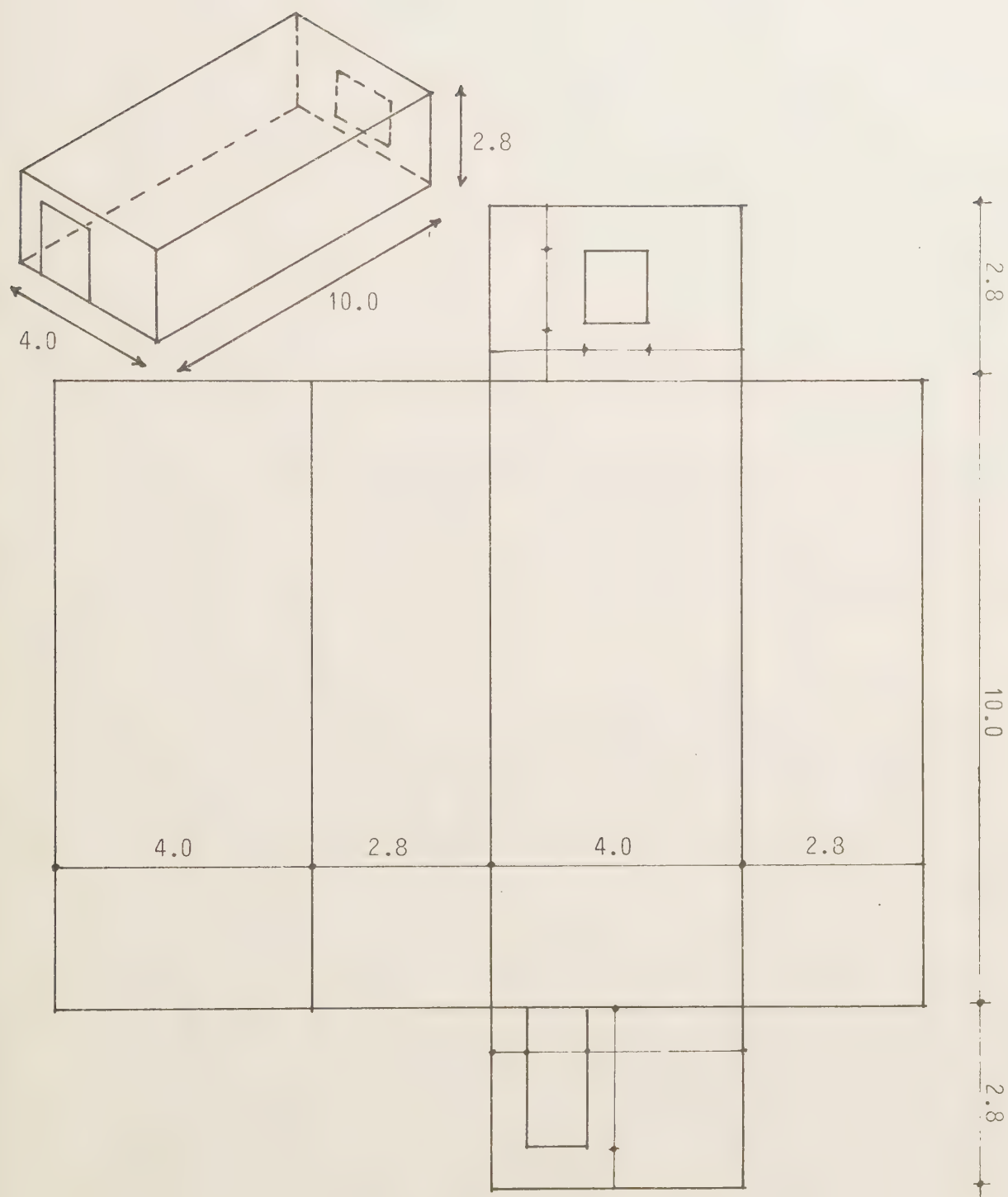


Figure 5.2.10 Dimensions of model (2).

From Table 5.2.4 it can be seen that when the wall is made of limestone 100 mm thick and the long axis runs north-south, the room air temperature is not more than 1.8°C lower than the maximum outdoor air temperature, which is 47.2°C . When the long axis runs east-west, the difference will be 3.5°C , even with the windows facing east, as in this case. This means that an east-west orientation of the long axis is preferable. This is related to the huge variation in the amount of solar radiation absorbed in the different surfaces of the building. In summer time, the northern surface receives twice as much total solar energy as the southern surface, and the western surface receives totally about 5 times as much as the southern surface (see Appendix 1).

Figure 5.2.11 shows the external surface temperature in the four cardinal directions. In the west, maximum external surface temperature is about 14°C above the maximum outdoor temperatures, while on the southern surface the difference is not more than 0.5°C . Obviously this has an effect on the inside surface temperature. It can be seen from Figure 5.2.13 that maximum inside surface temperature of the western surface is about 4.5°C higher than maximum inside surface temperature of the southern surface.

It can also be noted from Figure 5.2.12, which shows the heat flow at internal surfaces, that the eastern surface starts to emit heat to the indoor space at about 0800 h (8 a.m.), while the western surface starts at about 1300 h (1 p.m.). It can be seen that the largest quantity of heat is received from the western surface and the lowest from the southern surface.

By studying the inner temperatures of a wall in different orientations (see Table 5.2.5), it can be seen that in a wall 800 mm thick facing south, the temperature at depth of 150 mm from the outside surface is about 7.3°C below the maximum outdoor temperature, but in a wall facing west it is only 2.1°C . It can also be seen that with a southerly or northerly orientation, the temperature reduction will not increase very much at a larger distance from the outside than 250 mm.

Table 5.2.4 Influence of orientation of long axis on indoor temperature

Wall type	Direction of long axis	Room air temperature	Inside surfaces temperature °C													
			Surface 1			Surface 2			Surface 3			Surface 4				
			Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean		
 Limestone 100 mm	N - S	45.4	33.9	39.7	45.2	32.0	38.8	46.4	32.1	39.4	49.7	32.2	40.1	45.9	32.1	40.0
	NE-SW	45.1	33.9	39.5	47.6	32.0	39.3	45.6	31.9	39.7	48.9	32.2	39.7	45.4	32.1	39.3
	E - W	43.7	33.5	38.7	48.9	31.8	39.3	44.9	31.6	39.3	45.3	31.8	38.6	44.3	31.7	38.9
	ES-WN	44.7	33.9	39.4	49.4	32.0	39.7	45.4	31.9	39.3	45.5	32.0	39.7	47.4	32.1	39.3
 Limestone 400 mm	N - S	40.3	38.8	39.6	39.9	38.3	39.1	40.3	38.6	39.5	40.8	38.9	39.9	40.7	38.9	39.8
	NE-SW	40.2	38.8	39.5	40.3	38.5	39.4	40.5	38.7	39.6	40.6	38.7	39.6	40.2	38.5	39.4
	E - W	39.5	38.2	38.9	40.2	38.3	39.2	40.1	38.2	39.2	39.7	37.9	38.8	39.3	37.7	38.5
	ES-WN	40.2	38.7	39.5	40.6	38.7	39.6	40.3	38.4	39.4	40.5	38.7	39.6	40.3	38.5	39.4

N = North, S = South, E = East, W = West

Outdoor air temperature; Maximum = 47.2 °C, minimum = 21.6 °C and mean = 34.4 °C.

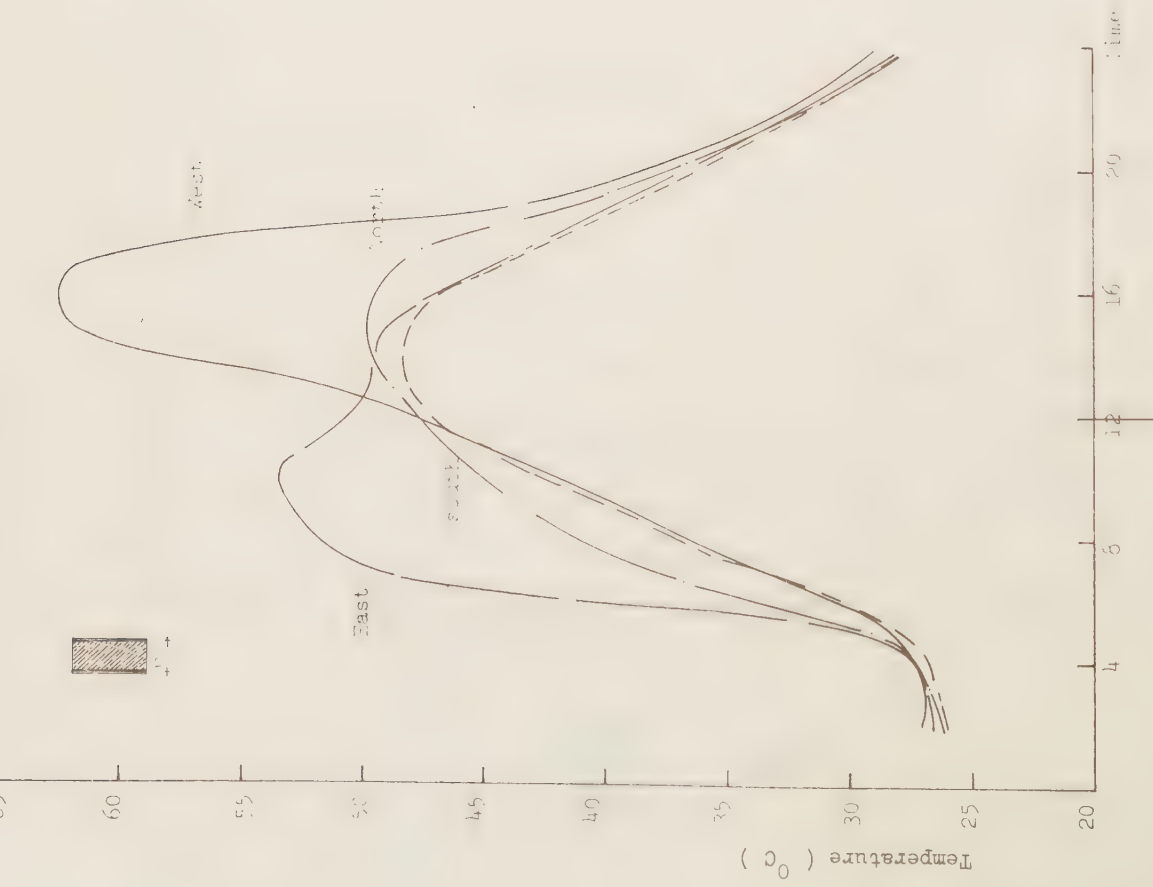


Figure 5.2.11 Influence of orientation on external surface temperature of a wall made of 100 mm limestone.

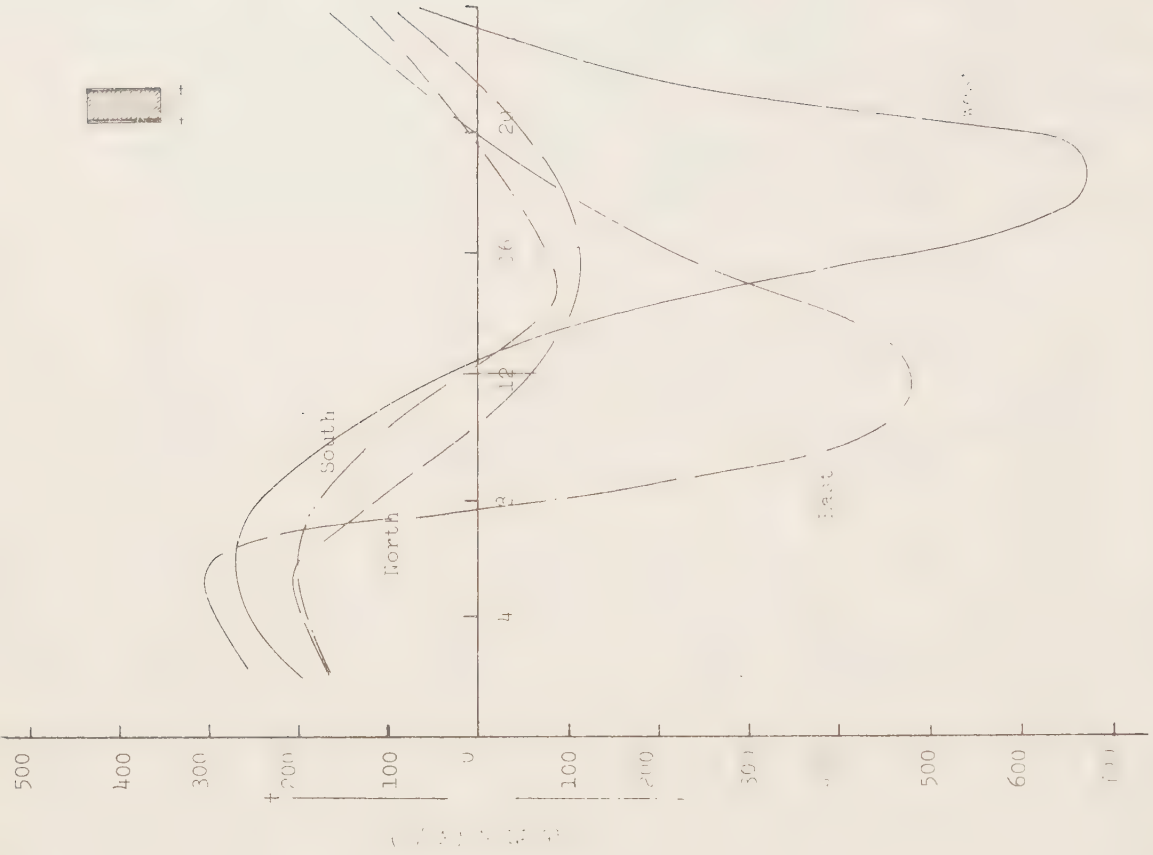


Figure 5.2.12 Influence of orientation on heat flow to internal surfaces of a wall made of 100 mm limestone.

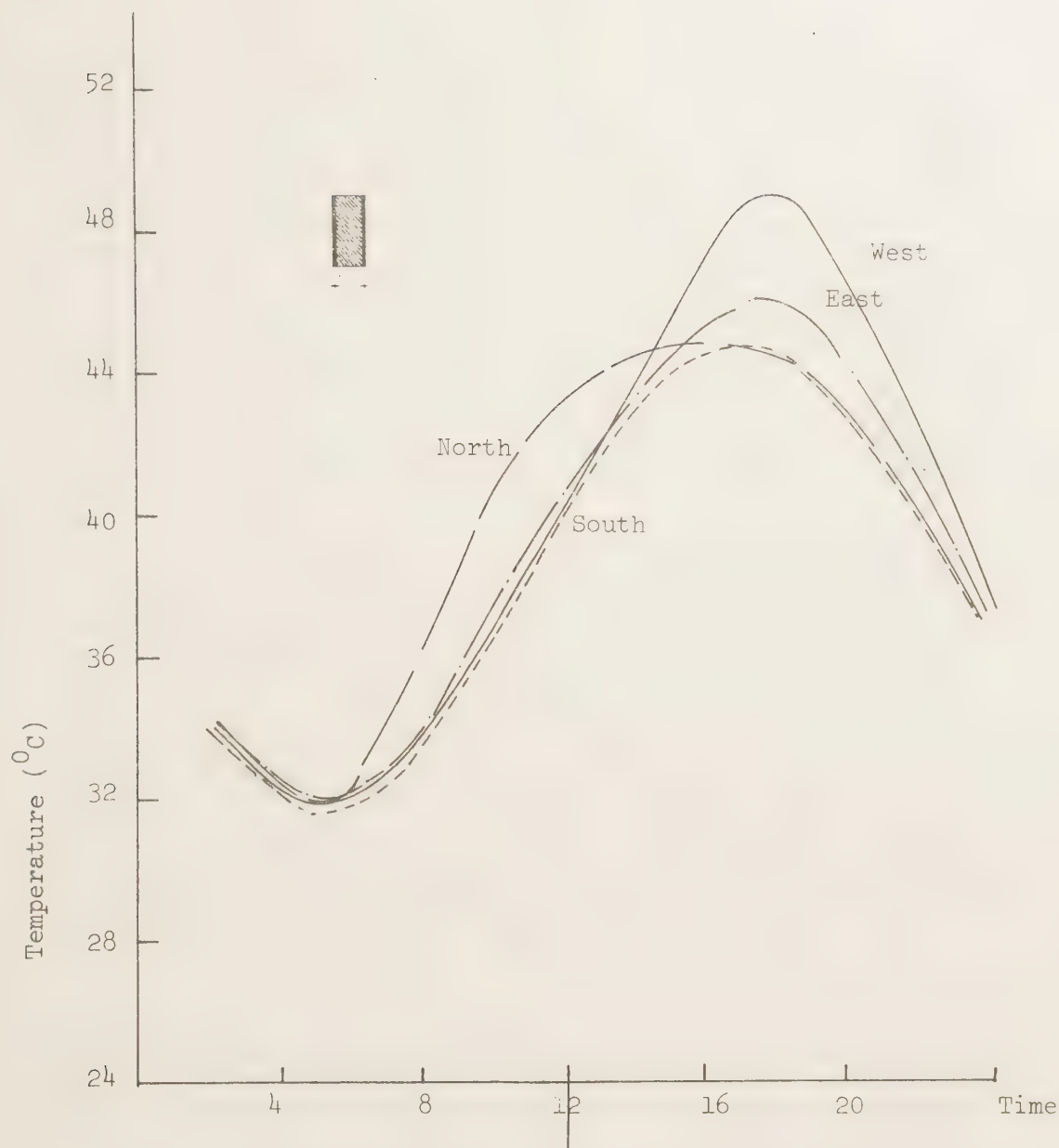


Figure 5.2.13 Influence of orientation on internal surfaces temperature, walls made of 100 mm limestone.

Table 5.2.5 Influence of thickness of wall on maximum temperature at different depths in the limestone walls.



Wall direction	Thickness mm	Depth of temperature point from outside surface															
		0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	800
South	200	-0.8	4.1		5.4	5.2											
	400	-0.8	4.1		6.9		7.9		7.8	7.6							
	600	-0.8	4.3		7.1		8.2		8.6		8.5		8.3	8.1			
	800	-0.8	4.4		7.3		8.6		9.0		9.0		9.0		8.8	8.5	8.1
North	200	-2.3	2.1		4.1	4.4											
	400	-2.4	2.3		5.4		6.9		7.2	7.2							
	600	-2.4	2.3		5.4		7.0		7.6		7.8		7.9	7.8			
	800	-2.4	2.4		5.5		7.2		7.9		8.2		8.2		8.2	8.1	7.9
West	200	-14.3	-3.9		1.1	2.9											
	400	-14.5	-4.1		2.3		5.3		6.2	6.7							
	600	-14.5	-4.2		2.1		5.0		6.3		6.9		7.3	7.6			
	800	-14.5	-4.2		2.1		5.0		6.3		6.9		7.3		7.6	7.7	7.6
East	200	-7.3	1.3		3.7	4.3											
	400	-7.6	0.8		4.2		5.9		6.5	6.8							
	600	-7.6	0.8		4.0		5.6		6.5		7.0		7.3	7.5			
	800	-7.6	0.7		4.0		5.6		6.5		7.1		7.4		7.6	7.7	7.7

Temperature reductions related to maximum outdoor air temperature (47.2 °C)

Changing the mode of room ventilation

Ventilation of a building can be supplied naturally through openings, as for example windows, but also with inlet and outlet openings in the building envelope. Ventilation can have a cooling effect if the outdoor air has a lower temperature than the interior of the building. This is the case during nights and ventilation during nights is consequently desirable. During the day the outdoor temperature in all practical cases in a hot arid climate will be higher than the indoor temperatures and ventilation should be avoided. In this section three types of ventilation will be studied:

no ventilation (infiltration 0.25 air changes per hour)

permanent ventilation

night ventilation (ventilated between 1900 and 0800, other times unventilated)

The thermal capacity of the building will obviously have an influence on the room temperatures in a night-ventilated building. Therefore, different thicknesses of the outer walls, assumed to be made of limestone, have been used in this study.

Table 5.2.6 shows results from computer calculations based on model (1) (Figure 5.1.1). In an unventilated building with walls of 100 mm limestone the maximum room air temperature reaches 45.4°C , only slightly below the outdoor maximum temperature = 47.2°C . With a permanent ventilation with 2.5 air changes per hour, the maximum room air temperature decreases to 44.3°C and with 5 air changes per hour to 44.1°C .

In the case of 400 mm walls of limestone the unventilated building will have a maximum room air temperature of 39.8°C , which is considerably lower than for 100 mm walls. Permanent ventilation will increase the maximum room air temperature. With 2.5 air changes per hour the temperature will reach 40.2°C and with 5 air changes per hour 41.1°C .

If night ventilation is applied the maximum room air temperature for the 400 mm wall case will decrease to 38.3°C at 2.5 air changes per hour and to 37.6°C at 5 air changes per hour, which should be compared

Table 5.2.6 Influence of ventilation conditions and rate of ventilation (air changes per hour) on room air temperature. Walls made of limestone.

Time of day	Out-door temp.	Room air temperature (°C) at									
		100 mm lime stone					400 mm lime stone				
		2.5 airch/h		5.0 airch/h		Un-vent.	2.5 airch/h		5.0 airch/h		Un-vent.
		perm. vent.	night vent.	perm. vent.	night vent.		perm. vent.	night vent.	perm. vent.	night vent.	
01.00	21.9	36.8	32.9	32.7	30.8	30.6	39.7	34.9	34.6	32.4	32.0
02.00	21.6	35.7	31.8	31.7	29.8	29.7	39.6	34.7	34.5	32.3	31.9
03.00	22.1	34.7	31.2	31.0	29.3	29.1	39.5	34.7	34.4	32.3	31.9
04.00	23.6	33.9	30.8	30.7	29.3	29.1	39.3	34.9	34.6	32.6	32.2
05.00	26.0	33.4	31.2	31.1	29.8	29.7	39.3	35.3	34.9	33.2	32.8
06.00	29.0	33.1	31.7	31.5	30.9	30.8	39.2	35.8	35.4	34.1	33.7
07.00	32.5	33.9	33.0	32.9	32.7	32.6	39.0	36.4	36.1	35.3	34.9
08.00	36.2	35.1	34.9	34.4	34.9	34.0	38.8	37.2	37.3	36.6	36.5
09.00	39.7	36.6	37.0	35.9	37.2	35.6	38.8	38.2	37.3	38.1	36.5
10.00	42.7	38.1	38.7	37.5	39.2	37.1	38.7	38.9	37.3	39.2	36.5
11.00	45.1	39.3	40.3	38.8	40.9	38.5	38.6	39.5	37.3	40.0	36.6
12.00	46.6	40.4	41.5	39.9	42.3	39.6	38.6	39.8	37.3	40.6	36.7
13.00	47.2	41.3	42.4	40.8	43.2	40.5	38.7	40.0	37.5	41.0	36.8
14.00	46.8	42.3	43.1	41.8	43.7	41.6	38.8	40.1	37.6	41.0	37.0
15.00	45.7	43.3	43.7	42.9	44.0	42.6	38.9	40.1	37.7	40.9	37.0
16.00	43.9	44.2	44.1	43.8	44.1	43.6	39.0	39.9	37.8	40.4	37.2
17.00	41.6	44.9	44.2	44.5	43.7	44.3	39.2	39.5	38.0	39.8	37.4
18.00	38.9	45.3	43.7	44.9	42.9	44.7	39.3	38.8	38.2	38.7	37.6
19.00	35.9	44.9	42.8	42.7	41.4	41.3	39.5	38.0	37.5	37.4	36.9
20.00	32.3	43.8	40.8	40.7	39.3	39.2	39.6	37.4	36.9	36.4	35.8
21.00	29.8	42.5	39.0	38.9	37.3	37.2	39.7	36.6	36.3	45.4	34.8
22.00	27.1	40.9	37.3	37.2	35.4	35.3	39.8	36.2	35.7	34.5	33.9
23.00	24.8	39.5	35.6	35.5	33.6	33.5	39.8	35.7	35.3	33.7	33.2
24.00	23.0	38.1	34.2	34.0	32.1	31.9	39.8	35.3	34.9	33.0	32.5

Night ventilation between 1900 and 0800, other times unventilated.

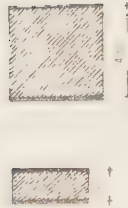


Table 5.2.7 Influence of night ventilation (air changes per hour) on room air temperature

and inside surfaces of walls facing south and west. The walls are made of limestone, 100 mm and 400 mm thick.

Time of day	Room air temperature			South surface temperature			West surface temperature		
	n=2.5			n=2.5			n=2.5		
	100mm	400mm	100mm	400mm	100mm	400mm	100mm	400mm	100mm
h	100mm	400mm	100mm	400mm	100mm	400mm	100mm	400mm	100mm
01.00	32.7	34.6	30.6	32.0	34.4	37.5	33.6	36.4	34.9
02.00	31.7	34.5	29.7	31.9	33.0	37.4	32.2	36.2	33.4
03.00	31.0	34.4	29.1	31.9	31.8	37.3	31.1	36.0	32.2
04.00	30.7	34.6	29.1	32.2	31.0	37.2	30.3	36.0	31.3
05.00	31.1	34.9	29.7	32.8	30.6	37.1	30.0	35.9	30.8
06.00	31.5	35.4	30.8	33.7	30.6	37.1	30.1	36.0	30.7
07.00	32.9	36.1	32.6	34.9	31.3	37.0	31.0	36.1	31.4
08.00	34.4	37.3	34.0	36.5	32.6	37.1	32.3	36.2	32.7
09.00	35.9	37.3	35.6	36.5	34.3	37.0	34.0	36.2	34.3
10.00	37.5	37.3	37.1	36.5	36.1	36.8	35.8	36.1	36.1
11.00	38.8	37.3	38.5	36.6	38.0	36.8	37.7	36.0	37.9
12.00	39.9	37.3	39.6	36.7	39.7	36.7	39.5	36.0	39.7
13.00	40.8	37.5	40.5	36.8	41.3	36.7	41.1	36.0	41.3
14.00	41.8	37.6	41.6	37.0	42.6	36.8	42.4	36.1	43.3
15.00	42.9	37.7	42.6	37.0	43.7	36.9	43.5	36.3	45.5
16.00	43.8	37.8	43.6	37.2	44.5	37.1	44.3	36.5	47.4
17.00	44.5	38.0	44.3	37.4	44.9	37.3	44.7	36.7	48.8
18.00	44.9	38.2	44.7	37.6	44.7	37.5	44.6	36.9	49.4
19.00	42.7	35.5	41.3	36.9	43.8	37.6	43.4	37.0	48.2
20.00	40.7	36.9	39.2	35.8	42.4	37.7	42.0	37.1	45.5
21.00	38.9	36.3	37.2	34.8	40.9	37.8	40.3	37.0	43.1
22.00	37.2	35.7	35.3	33.9	39.3	37.8	38.6	36.9	40.8
23.00	35.5	35.3	33.5	33.2	37.6	37.7	36.9	36.7	38.7
24.00	34.0	34.9	31.9	32.5	35.9	37.7	35.2	36.5	36.7

Night ventilation with n air changes per hour between 1900 and 0800. Other times unventilated.

with 39.8°C achieved in an unventilated building. The minimum room air temperature is 34.5°C at 2.5 air changes per hour and 31.9°C at 5 air changes per hour, compared with 38.7°C in an unventilated building.

The effect of night ventilation in a building with 100 mm walls of limestone is small. At 5 air changes per hour the room air temperature is at maximum 44.7°C and at minimum 29.2°C compared with 45.0°C and 33.2°C , respectively, in an unventilated building.

Table 5.2.8 shows the inside surface temperatures on 100 and 400 mm limestone walls at different rates of night ventilation. It is obvious that night ventilation must be compared with a good thermal storage capacity if reasonable indoor temperatures are to be obtained.

Table 5.2.8 Influence of ventilation rate at night¹⁾ on maximum and minimum indoor temperature

Wall type	n airchange per hour	Room air temp	Inside surface temperature (°C)																
			South		North		West		East		Roof		Floor		Window		Door		
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
 100 mm Limestone	Unvent.	45.4	33.2	45.2	31.5	46.4	31.6	49.8	31.7	45.9	31.6	42.9	37.1	42.2	35.5	44.5	30.4	45.6	32.5
	n=2.5	45.0	30.7	44.9	30.6	46.1	30.6	49.4	30.7	45.5	30.6	42.2	36.3	41.5	34.3	44.2	29.1	45.2	31.4
	n=5	44.7	29.2	44.7	30.0	45.9	30.1	49.2	30.2	45.3	30.1	41.8	35.9	41.2	33.5	44.1	28.4	45.0	30.7
	n=10	44.5	27.1	44.5	29.3	45.7	29.4	49.1	29.5	45.1	29.4	41.5	35.4	40.8	32.6	43.9	27.8	44.7	29.9
 400 mm Limestone	Unvent.	39.9	38.7	39.6	38.1	40.0	38.4	40.5	38.7	40.4	38.6	40.9	38.4	39.5	38.7	42.5	33.0	41.5	36.6
	n=2.5	38.3	34.5	37.8	36.8	38.1	37.0	38.5	37.4	38.6	37.3	39.7	37.1	37.8	36.9	41.7	31.0	40.5	34.4
	n=5	37.6	31.9	37.1	35.9	37.4	36.3	37.6	36.7	37.9	36.5	39.0	36.4	37.1	35.5	41.3	29.9	39.9	33.3
	n=10	36.9	28.9	36.4	34.6	36.7	34.9	36.9	35.3	37.3	35.1	38.3	35.6	36.3	33.9	40.8	28.9	39.3	31.9

1) 1900-0800

5.2.2 Influence of thermal insulation of walls

First I would like to review some opinions from the literature: In a building without air conditioning, increase of the thermal resistance of the wall will reduce the heat flow from external surfaces into the indoor space during the daytime and out of it at night. The effect of increased resistance depends on the location of the insulation - whether it is outside or inside layer of the envelope (Conklin, 1953).

Rapp,(1952) has said "Use of insulation has not been adequately tested, so that its practical benefits cannot be accurately assessed at the present time. Possibly more research is needed in this direction".

The choice of insulation materials for excluding the heat in summer should not be made on thermal conductivity value alone, but also with consideration to other properties such as density and specific heat (Richards and Lots, 1964, and Givoni, 1976).

Three kinds of insulation have been chosen for this study. They have different values for thermal conductivity and density: heavy mineral wool slabs which have low conductivity and high density, expanded polystyrene which has low conductivity and low density, and wood fibre slabs with high conductivity and high density.

In modern buildings insulation materials are used in hot climates. Therefore the influence of the combination between thermal capacity and insulation on the thermal performance of a building under conditions of large daily variations in outdoor temperature must be considered.

This study will show the effect on indoor temperature of a double wall in combination with various insulation materials. Three aspects will be considered:

- influence of insulation thickness
- influence of position of insulation
- influence of type of insulation

Design alternatives and thermal nets are shown in Table 5.2.9.

Influence of insulation thickness

The effect of different thicknesses of wall insulation is summarized in Table 5.2.10, which shows a comparison between room air temperatures in a room with a double brick wall and rooms with walls made of double brick with 50 mm, 100 mm and 200 mm of mineral wool in the middle. It can be seen that the daily mean, T_{av} , and the daily swing, ΔT , of the room air temperature are:

with	0 mm insulation	$T_{av} = 39.4$ °C	and	$\Delta T = 5.1$ °C
	50 mm	= 39.2		= 1.2
	100 mm	= 39.1		= 0.7
	200 mm	= 39.1		= 0.7

The insulation thickness will only slightly affect the average temperature but an increase of insulation from 0 to 50 mm thickness will decrease the temperature swing ΔT from 5.1 °C to 1.2 °C.

It can also be seen that the difference between maximum outdoor air temperature (47.2 °C) and the maximum room air temperature is about 5.3, 7.4, 7.7 and 7.8 °C respectively. Regarding minimum room air temperature, the difference is about 15.3, 17.0, 17.2 and 17.1 °C respectively above the minimum outdoor temperature, 21.6 °C. This means that increasing the thickness of the insulation has an effect on maximum and minimum indoor temperature, but there is a limit to its effectiveness. An increase of the insulation thickness to more than 50 mm will not give much benefit.

By comparing the heat flow to the inner surface of the wall facing west (Figure 5.2.14), it can be seen that the insulation decreases the heat flow and an increase in the thickness of insulation after 50 mm is practically insignificant for the amplitude of the heat flow. This demonstrates that increasing the thermal resistance reduces the heat flow across the wall and generally lowers the internal temperature, but above a certain level of resistance, any increase gives only

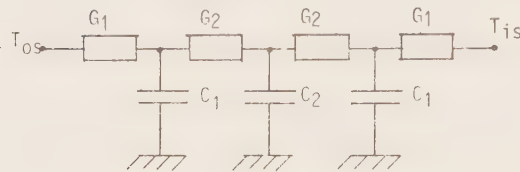
Table 5.2.9 Thermal nets for insulated walls

1) Double red brick with 50 mm mineral wool slabs



$$G_1 = 11.14 \cdot A \quad \text{W/}^\circ\text{C} \quad C_1 = 48.38 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 2.06 \cdot A \quad \text{W/}^\circ\text{C} \quad C_2 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

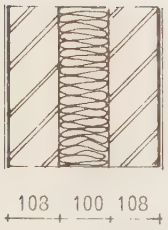


A = area of wall surface

T_{OS} = outside surface temperature

T_{IS} = inside surface temperature

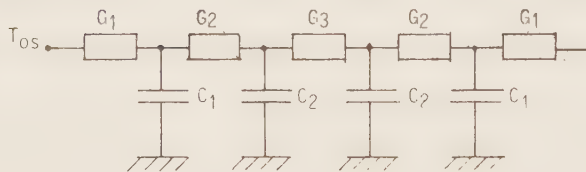
2) Double red brick 100 mm mineral wool slabs



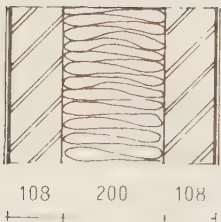
$$G_1 = 11.14 \cdot A \quad \text{W/}^\circ\text{C} \quad C_1 = 48.38 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 2.06 \cdot A \quad \text{W/}^\circ\text{C} \quad C_2 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_3 = 1.16 \cdot A \quad \text{W/}^\circ\text{C}$$



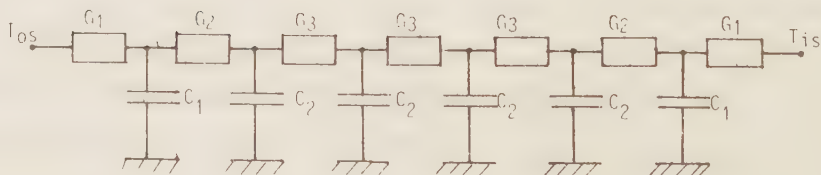
3) Double red brick with 200 mm mineral wool slabs



$$G_1 = 11.14 \cdot A \quad \text{W/}^\circ\text{C} \quad C_1 = 48.38 \cdot A \quad \text{Wh/}^\circ\text{C}$$

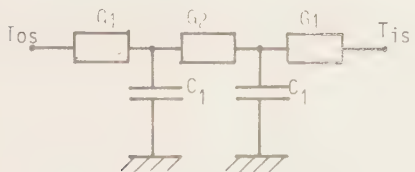
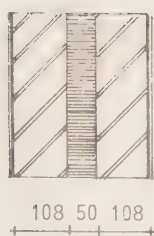
$$G_2 = 2.06 \cdot A \quad \text{W/}^\circ\text{C} \quad C_2 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_3 = 1.16 \cdot A \quad \text{W/}^\circ\text{C}$$



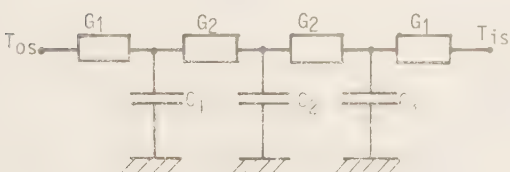
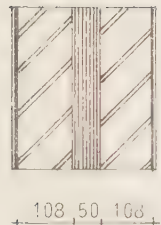
4) Double red brick with 50 mm polystyrene slab

$G_1=11.13 \cdot A \quad W/^{\circ}C$ $C_1=48.4 \cdot A \quad Wh/^{\circ}C$
 $G_2=0.63 \cdot A \quad W/^{\circ}C$



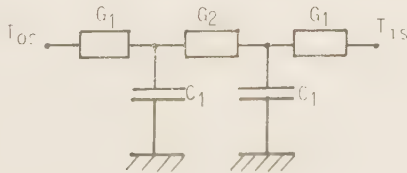
5) Double red brick with 50 mm fibre slab

$G_1=11.13 \cdot A \quad W/^{\circ}C$ $C_1=48.4 \cdot A \quad Wh/^{\circ}C$
 $G_2=5.5 \cdot A \quad W/^{\circ}C$ $C_2=15.8 \cdot A \quad Wh/^{\circ}C$



6) Double red brick with 50 mm air space

$G_1=11.14 \cdot A \quad W/^{\circ}C$ $C_1=48.38 \cdot A \quad Wh/^{\circ}C$
 $G_2=3.597 \cdot A \quad W/^{\circ}C$



7) Double hollow red brick with 50 mm mineral wool slab

$G_1=7.185 \cdot A \quad W/^{\circ}C$ $C_1=30.2 \cdot A \quad Wh/^{\circ}C$
 $G_2=1.871 \cdot A \quad W/^{\circ}C$ $C_2=4.95 \cdot A \quad Wh/^{\circ}C$

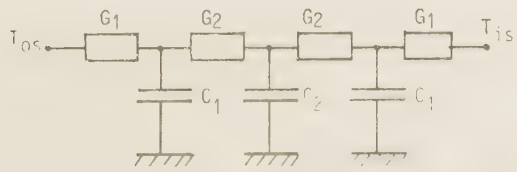
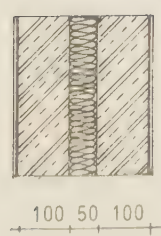


Table 5.2.9 (cont'd)

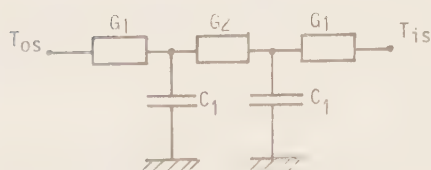
8) Double hollow red brick with 50 mm air space

$$G_1 = 7.185 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 30.2 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 2.65 \cdot A \quad \text{W/}^\circ\text{C}$$

resistance of an air layer = $0.17 \text{ }^\circ\text{C}\cdot\text{m}^2/\text{W}$



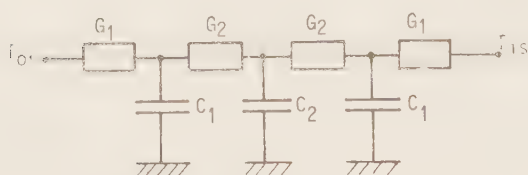
9) Double concrete with 50 mm mineral wool slab

$$G_1 = 14.166 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 67.0 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 2.147 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

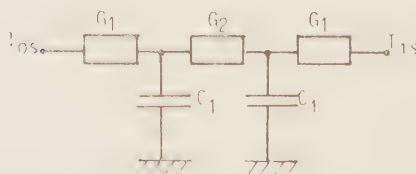


10) Double concrete wall with 50 mm air space

$$G_1 = 14.166 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 67.0 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 4.175 \cdot A \quad \text{W/}^\circ\text{C}$$



11) Double brick with 50 mm polystyrene slab on the
outside

$$G_1 = 0.64 \cdot A \quad \text{W/}^\circ\text{C}$$

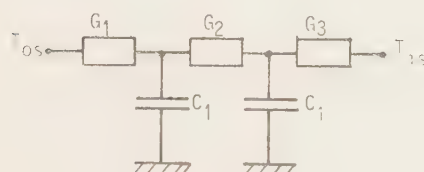
$$G_2 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_3 = 11.135 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 48.4 \cdot A \quad \text{Wh/}^\circ\text{C}$$



50 216



12) Double red brick with 50 mm mineral wool slab outside

$$G_1 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$

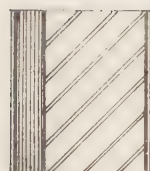
$$G_2 = 2.06 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_3 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

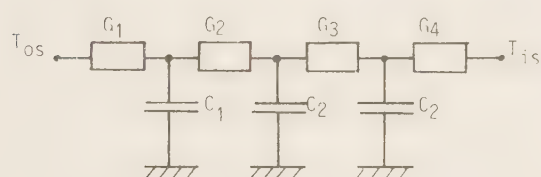
$$G_4 = 11.135 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$C_2 = 48.4 \cdot A \quad \text{Wh/}^\circ\text{C}$$



50 216



13) Double red brick with 50 mm wood fibre slab on the
outside

$$G_1 = 6.9 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_2 = 5.49 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_3 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_4 = 11.135 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 15.8 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$C_2 = 48.4 \cdot A \quad \text{Wh/}^\circ\text{C}$$



50 216

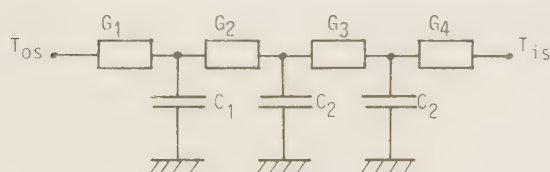


Table 5.2.9 (cont'd)

14) Double red brick with 50 mm mineral wool slab on the inside

$$G_1 = 11.155 \cdot A \quad \text{W/}^\circ\text{C}$$

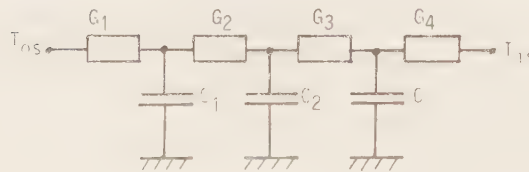
$$C_1 = 48.34 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_3 = 2.06 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_4 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$



15) Single hollow red brick with 100 mm mineral wool and 50 mm air space between

$$G_1 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$

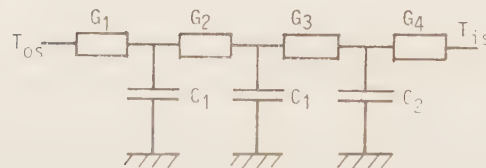
$$C_1 = 4.95 \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 1.16 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 30.2 \quad \text{Wh/}^\circ\text{C}$$

$$G_3 = 1.419 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_4 = 7.185 \cdot A \quad \text{W/}^\circ\text{C}$$



16) Cavity wall ventilated, and made of outside layer 50 mm mineral wool and inside layer 100 mm lime stone

$$G_1 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 4.94 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 11.17 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 41.5 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_r = 5.2 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_v = 0.35 \cdot n \cdot v \quad \text{W/}^\circ\text{C}$$

$$G_c = 2.5 \cdot A \quad \text{W/}^\circ\text{C}$$

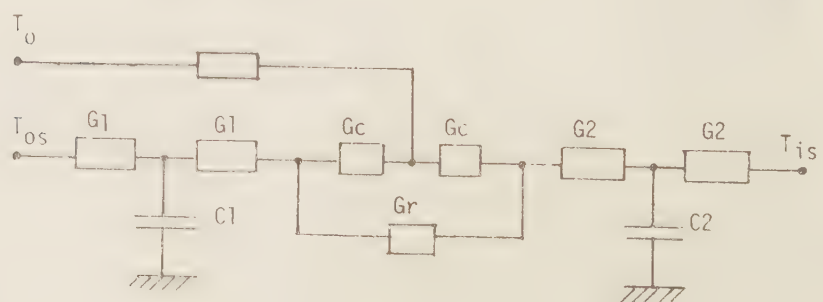
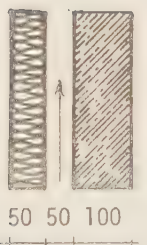


Table 5.2.9 (cont'd)

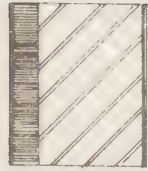
11) Double brick with 50 mm polystyrene slab on the
outside

$$G_1 = 0.64 \cdot A \quad \text{W/}^\circ\text{C}$$

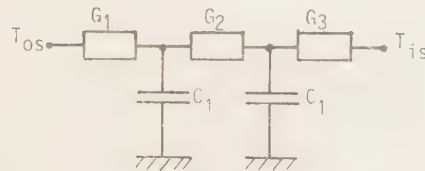
$$G_2 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_3 = 11.135 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 48.4 \cdot A \quad \text{Wh/}^\circ\text{C}$$



50 216



12) Double red brick with 50 mm mineral wool slab outside

$$G_1 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_2 = 2.06 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_3 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

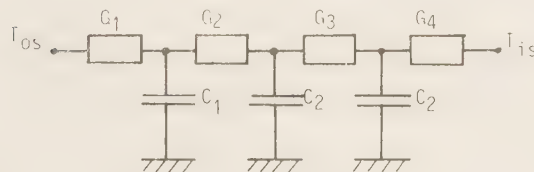
$$G_4 = 11.135 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$C_2 = 48.4 \cdot A \quad \text{Wh/}^\circ\text{C}$$



50 216



13) Double red brick with 50 mm wood fibre slab on the
outside

$$G_1 = 6.9 \cdot A \quad \text{W/}^\circ\text{C}$$

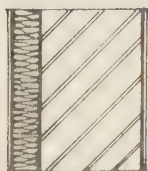
$$G_2 = 5.49 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_3 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_4 = 11.135 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 15.8 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$C_2 = 48.4 \cdot A \quad \text{Wh/}^\circ\text{C}$$



50 216

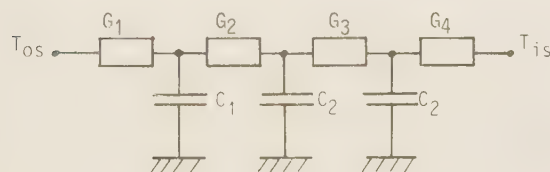


Table 5.2.9 (cont'd)

14) Double red brick with 50 mm mineral wool slab on the inside

$$G_1 = 11.155 \cdot A \quad \text{W/}^\circ\text{C}$$

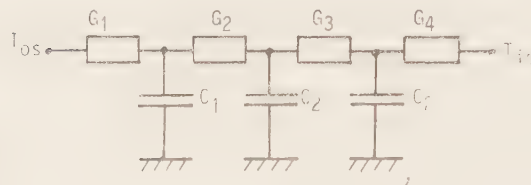
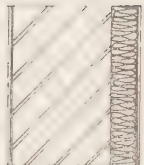
$$C_1 = 48.34 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 9.27 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 4.95 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_3 = 2.06 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_4 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$



15) Single hollow red brick with 100 mm mineral wool and 50 mm air space between

$$G_1 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$

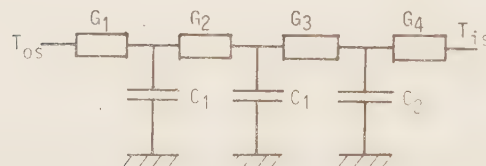
$$C_1 = 4.95 \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 1.16 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 30.2 \quad \text{Wh/}^\circ\text{C}$$

$$G_3 = 1.419 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_4 = 7.185 \cdot A \quad \text{W/}^\circ\text{C}$$



16) Cavity wall ventilated, and made of outside layer 50 mm mineral wool and inside layer 100 mm lime stone

$$G_1 = 2.14 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_1 = 4.94 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_2 = 11.17 \cdot A \quad \text{W/}^\circ\text{C}$$

$$C_2 = 41.5 \cdot A \quad \text{Wh/}^\circ\text{C}$$

$$G_r = 5.2 \cdot A \quad \text{W/}^\circ\text{C}$$

$$G_v = 0.35 \cdot n \cdot v \quad \text{W/}^\circ\text{C}$$

$$G_c = 2.5 \cdot A \quad \text{W/}^\circ\text{C}$$

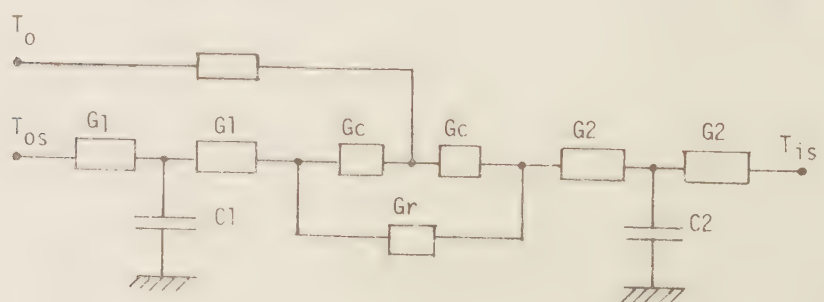
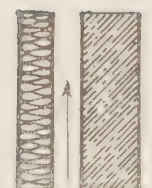
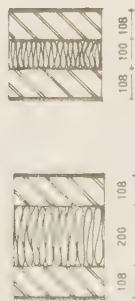


Table 5.2.10 Influence of thickness of mineral wool insulation between double red brick on the room air temperature.

Time of day h	Room air temperatur (°C)			
	without insula- tion	mineral wool 50 mm	mineral wool 100 mm	mineral wool 200 mm
01.00	40.1	39.5	39.2	38.9
02.00	39.5	39.4	39.1	38.8
03.00	38.9	39.3	39.0	38.8
04.00	38.3	39.1	38.9	38.7
05.00	37.8	39.0	38.9	38.7
06.00	37.3	39.9	38.8	38.7
07.00	37.1	38.8	38.8	38.7
08.00	36.8	38.6	38.8	38.7
09.00	36.9	38.5	38.7	38.7
10.00	37.1	38.5	38.7	38.7
11.00	37.5	38.5	38.7	38.8
12.00	37.9	38.6	38.8	38.9
13.00	38.5	38.8	38.9	39.0
14.00	39.0	39.0	39.0	39.2
15.00	39.7	39.1	39.1	39.2
16.00	40.2	39.3	39.2	39.3
17.00	40.7	39.4	39.3	39.3
18.00	41.3	39.5	39.4	39.4
19.00	41.7	39.6	39.4	39.4
20.00	41.9	39.7	39.4	39.3
21.00	41.9	39.7	39.4	39.2
22.00	41.6	39.8	39.4	39.2
23.00	41.3	39.7	39.3	39.1
24.00	40.8	39.7	39.3	39.1



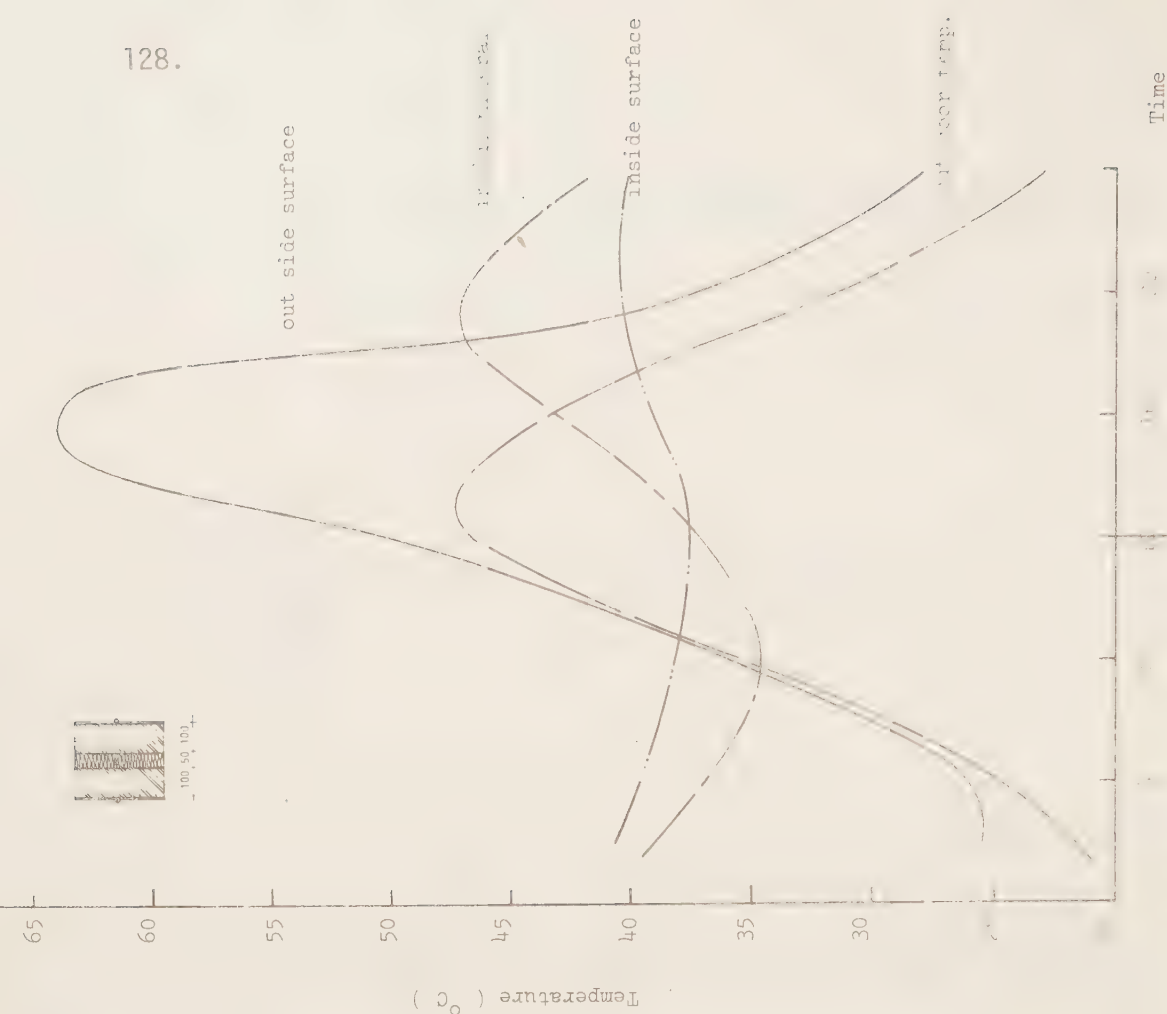


Figure 5.2.15 Temperatures of external and internal surface and in the middle of mineral wool. The wall is facing west and made of double hollow brick with 50 mm mineral wool insulation.

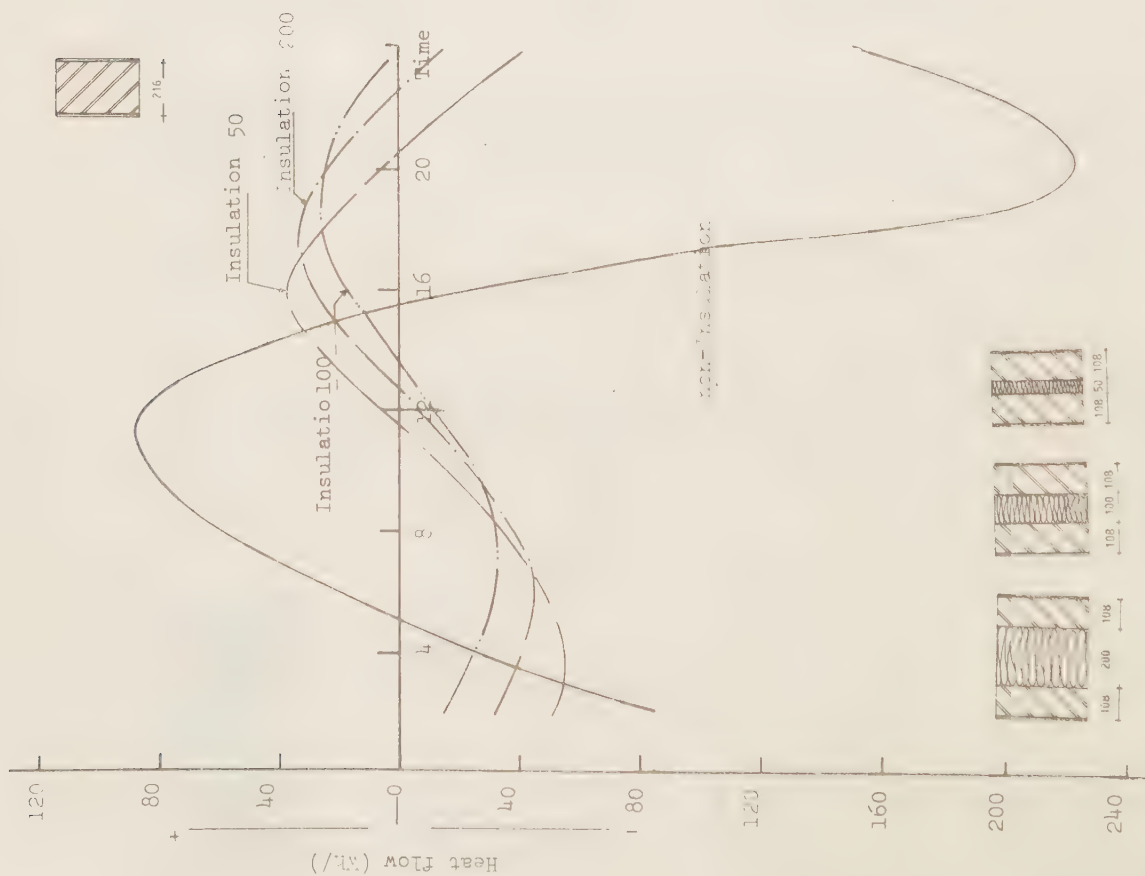


Figure 5.2.14 Influence of insulation thickness on heat flow at internal surface of a wall facing west, made of double brick with 50, 100 and 200 mm mineral wool insulation.

a small effect on the indoor temperature.

In the case of an insulated wall facing south, it can be seen in Figure 5.2.16 that increasing the insulation thickness has the disadvantage of reducing the heat flow outwards.

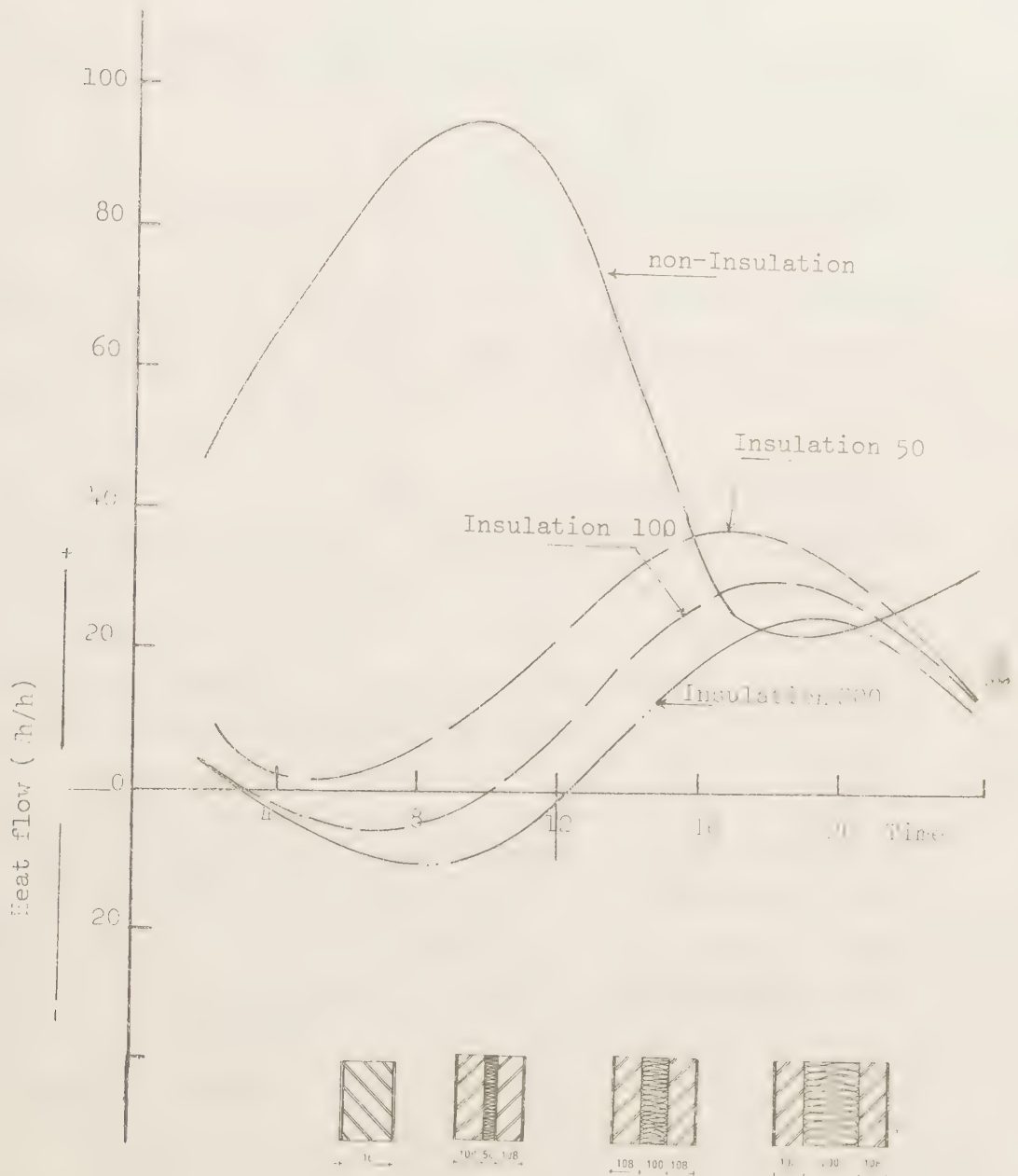


Figure 5.2.16 Influence of thickness of insulation on heat flow at internal surfaces of wall facing south, made of double brick without insulation and with 50, 100 and 200 mm mineral wool sandwiched.

In order to decrease the room air temperatures during the day, the room can be strongly ventilated during the night and have minimum ventilation during the day. Obviously the wall insulation will have an influence also for night ventilation cases. In Table 5.2.11 the room air temperatures and the inside surface temperature of the west wall are shown. The maximum temperatures are:

	Room air temp.	Inside surface temp.
no insulation	40.1 °C	41.7 °C
50 mm mineral wool	37.0	36.9
100 mm mineral wool	36.3	36.2
200 mm mineral wool	35.9	35.6

It can be seen that up to 100 mm insulation gives a considerable effect on the room temperatures.

Influence of position of the insulation

The position of the wall insulation also has an influence on the room temperatures. Table 5.2.12 shows three positions of insulation, 1) inside and 2) outside insulation as well as 3) insulation in the center of the wall. The mean room air temperature has approximately the same mean value for all the cases, but insulation on the inside gives the highest maximum room air temperature, 0.7 °C above what is achieved for center or outside positions, which are equal. Similar results are obtained for the inside surface temperature of the walls. The maximum inside surface temperature occurs when the insulation is placed on the internal surface, i.e. 0.9 °C higher than with the insulation placed on the external surface of the wall facing west.

With inside insulation the maximum room air temperature appears $\frac{1}{2}$ -1 hour later than with outside insulation, see Table 5.2.13.

Table 5.2.11 Influence of thickness of mineral wool insulation between two brick walls in the case of night ventilation of the room, 5 air changes per hour between 1900 and 0800.

Time of day (h)	Room air temperature (°C)		Inside surface temp. (west wall) (°C)				
	without insulation	thickness of insulation (mm)		without insulation	thickness of insulation (mm)		
		50	100		50	100	200
01.00	32.6	31.4	31.0	38.2	36.0	35.3	34.3
02.00	32.0	31.1	30.8	37.4	35.7	35.1	34.2
03.00	31.7	31.1	30.8	36.6	35.5	35.0	34.0
04.00	31.7	31.5	31.2	35.9	35.4	34.9	34.0
05.00	32.2	32.1	31.9	35.3	35.3	35.0	34.1
06.00	32.9	33.0	32.8	35.0	35.3	35.1	34.3
07.00	34.0	34.2	34.1	34.8	35.4	35.2	34.5
08.00	34.9	35.3	35.3	34.7	35.5	35.3	34.6
09.00	35.1	35.4	35.3	34.7	35.4	35.3	34.7
10.00	35.5	35.5	35.4	34.9	35.4	35.3	34.8
11.00	35.9	35.6	35.5	35.3	35.4	35.4	34.8
12.00	36.5	35.8	35.7	35.8	35.4	35.4	34.9
13.00	37.1	35.9	35.7	36.5	35.6	35.5	35.0
14.00	37.7	36.0	35.8	37.2	35.7	35.6	35.1
15.00	38.3	36.3	36.1	38.0	35.9	35.7	35.2
16.00	38.9	36.4	36.2	39.0	36.1	35.8	35.3
17.00	39.5	36.6	36.2	40.0	36.3	35.9	35.4
18.00	40.1	36.9	36.3	41.0	36.6	36.1	35.5
19.00	38.6	36.4	36.1	41.5	36.8	36.2	35.6
20.00	37.6	35.3	35.0	41.7	36.9	36.1	35.5
21.00	36.6	34.3	33.9	41.3	36.8	36.0	35.3
22.00	35.4	33.4	33.0	40.7	36.7	35.8	35.1
23.00	34.4	32.6	32.1	40.0	36.5	35.7	34.8
24.00	33.4	31.9	31.5	39.1	36.3	35.3	34.6

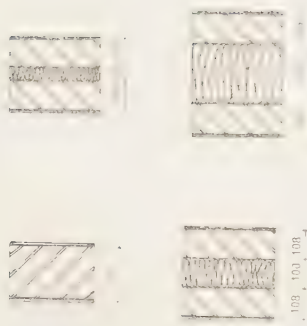


Table 5.2.12 Influence of position of insulation on maximum, minimum and mean indoor temperature (50 mm mineral wool insulation with 216 mm red brick wall).



Position of insulation	Room air temperature		Inside surface temperature ($^{\circ}\text{C}$)													
			South				North				West				East	
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	
Inside	40.6	37.9	39.3	40.5	37.6	39.1	40.8	37.7	39.2	41.1	37.9	39.4	40.9	37.9	39.4	
Center	39.9	38.6	39.2	39.7	38.4	39.0	39.9	38.5	39.2	40.2	38.6	39.4	40.1	38.6	39.4	
Outside	39.9	38.2	39.1	39.7	38.4	39.1	39.9	38.6	39.2	40.2	38.6	39.4	40.1	38.7	39.4	

Table 5.2.13 Influence on indoor temperature of position and type of insulation 50 mm thick with wall 216 mm red brick.

Time of day	Room air and inside surface temperature (°C)											
	Mineral wool				Polystyrene				Wood fibers			
	Outside		Inside		Outside		Inside		Outside		Inside	
	room	west	room	west	room	west	room	west	room	west	room	west
h	room	west	room	west	room	west	room	west	room	west	room	west
01.00	39.4	39.9	39.8	40.4	39.6	40.1	39.5	39.9	39.9	40.7	40.2	41.1
02.00	39.3	39.8	39.5	40.0	39.6	40.0	39.2	39.6	39.7	40.4	40.0	40.7
03.00	39.1	39.6	39.2	39.7	39.4	39.8	38.8	39.2	39.4	40.1	39.4	40.3
04.00	38.9	39.5	38.9	39.3	39.3	39.7	38.6	38.9	39.1	39.8	39.2	39.8
05.00	38.8	39.3	38.6	39.0	39.1	39.6	38.3	38.6	38.8	39.4	38.7	39.3
06.00	38.7	39.1	38.4	38.6	39.1	39.4	38.1	38.3	38.6	39.1	38.5	38.8
07.00	38.7	39.0	38.1	38.3	39.0	39.3	38.1	38.1	38.4	38.8	38.1	38.4
08.00	38.6	38.0	38.0	38.1	39.0	39.3	38.0	38.0	38.2	38.5	38.0	38.0
09.00	38.6	38.7	37.9	37.9	39.0	39.2	38.0	37.9	38.2	38.3	37.7	37.7
10.00	38.6	38.7	38.0	37.8	39.1	39.2	38.1	38.0	38.1	38.1	37.7	37.5
11.00	38.7	38.7	38.1	37.9	39.2	39.2	38.3	38.1	38.2	38.1	37.8	37.5
12.00	38.8	38.7	38.3	38.1	39.3	39.3	38.5	38.4	38.4	38.1	38.0	37.6
13.00	39.0	38.8	38.6	38.3	39.4	39.4	38.8	38.7	38.5	38.3	38.2	37.8
14.00	39.2	38.9	38.9	38.7	39.6	39.5	39.1	39.0	38.8	38.5	38.5	38.2
15.00	39.3	39.1	39.2	39.0	39.8	39.6	39.5	39.4	39.0	38.7	39.0	38.5
16.00	39.4	39.2	39.6	39.4	39.9	39.8	39.8	39.8	39.4	39.1	39.3	39.0
17.00	39.6	39.4	39.9	39.8	40.0	39.9	40.1	40.1	39.6	39.4	39.7	39.5
18.00	39.7	39.6	40.1	40.2	40.1	40.1	40.3	40.4	39.9	39.8	40.0	40.1
19.00	39.8	39.8	40.3	40.5	40.1	40.2	40.4	40.7	40.1	40.3	40.4	40.6
20.00	39.8	40.0	40.5	40.8	40.1	40.3	40.5	40.8	40.2	40.6	40.6	41.1
21.00	39.8	40.1	40.6	41.0	40.1	40.3	40.4	40.8	40.3	40.9	40.8	41.5
22.00	39.8	40.2	40.5	41.0	40.0	40.3	40.3	40.7	40.3	41.1	40.8	41.6
23.00	39.7	40.1	40.3	40.9	39.9	40.2	40.1	40.5	40.2	41.0	40.7	41.6
24.00	39.5	40.1	40.1	40.7	39.7	40.1	39.8	40.2	40.1	40.9	40.5	41.4

The outside surface temperature is of course much higher when the outside of the wall is insulated (Table 5.2.14); the highest outside surface temperature occurs on a west wall surface with outside insulation and the lowest on a south wall's surface with inside insulation.

The results above are confirmed by Table 5.2.15, showing the heat flow to the inside surface. South-oriented walls have positive heat flow with small differences between the insulation position. West-oriented walls have large negative heat flows (from inside surface to the room), the largest for a wall with inside insulation.

It is obvious that insulation on the outside surface will reduce the heat flow rate into the wall. Consequently less heat will flow to the indoors. From Figure 5.2.17 it can be seen that when 50 mm mineral wool insulation is placed on the outside of a 216 mm thick wall of red brick, maximum external surface temperature will be 21.3°C above maximum outdoor temperature (47.2°C). At a depth of 127 mm from the outside surface, the temperature will be 6.0°C lower than maximum outdoor temperature. When the insulation is placed on the internal surface of the wall, maximum external surface temperature will be about 14°C above maximum outdoor temperature and at a depth of 187 mm from the outside surface, the temperature will be 1.9°C lower than the maximum outdoor temperature.

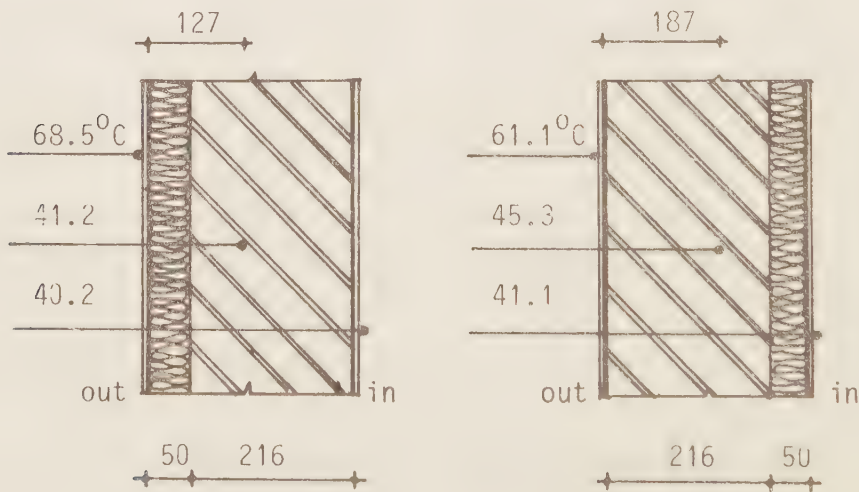


Figure 5.2.17 Influence of position of insulation on indoor temperature.

Table 5.2.15 Influence of position of insulation on heat flow to internal surfaces in different orientation (50 mm mineral wool insulation with 216 mm red brick wall).

Position of insulation	Heat flow (W)							
	South		North		West		East	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Inside	35.5	4.4	24.6	-12.1	24.0	-62.0	22.8	-38.5
Center	36.5	2.7	26.3	-11.1	33.1	-56.9	-6.3	-29.2
Outside	32.1	7.4	21.3	-4.6	22.3	-44.4	-6.4	-21.8

Insulation material

Three types of insulation material have been examined

mineral wool slabs	$\lambda = 0.058 \text{ W/}^{\circ}\text{C,m}$	$c \cdot \rho = 99 \text{ Wh/}^{\circ}\text{C,m}^3$
polystyrene slabs	$= 0.034$	$= 23$
wood fibre slabs	$= 0.197$	$= 316$

where λ = thermal conductivity ($\text{W/}^{\circ}\text{C,m}$)

c = specific heat ($\text{Wh/}^{\circ}\text{C,kg}$)

ρ = density (kg/m^3)

In Table 5.2.16 50 mm of the insulation material is placed on the outside of a red brick wall, 216 mm thick. The highest maximum room air temperature occurs with wood fibre insulation and the lowest with mineral wool insulation. Similar results are also reached for the inside surface temperatures. The effect of insulation material is obviously a combination of insulation properties and storage properties.

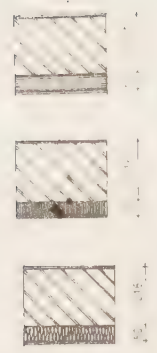
The outside surface temperature of the wall is highest for polystyrene insulated walls, independent of orientation (Table 5.2.17). For such a wall facing west, surface temperatures up to 70°C can be achieved even with an absorptivity not more than $a=0.5$.

The heat flows in Table 5.2.18 also confirm that wood fibre slabs will provide the room air with more heat than the other materials. The same results are shown in Table 5.2.19, where the insulation is placed in the center of the wall.

Table 5.2.20 shows that the wall material has a negligible influence on room air temperature and on the inside surface temperature if the insulating material is placed in the middle of the wall.

Since air costs nothing, it might be used as insulation against heat transfer. The main heat transfer across air space is by radiation from a warm surface to a colder surface and the remainder by convection current within the air space itself. The resistance is about $0.17^{\circ}\text{C,m}^2/\text{W}$.

Table 5.2.16 Influence of insulation material on maximum and minimum indoor temperature.
Comparison between walls made of double red brick (216 mm) externally covered
by 50 mm mineral wool, expanded polystyrene or wood fibre slabs (50 mm).



Type of insulation	Room air temperature		Internal surface temperature (°C)												
			South				North				West				
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean			
Mineral wool slab	39.9	38.6	39.2	39.7	38.4	39.1	39.9	38.6	39.2	40.2	38.7	39.4	40.1	38.7	39.4
Polystyrene slab	40.2	39.1	39.6	40.0	39.1	39.5	40.2	39.2	39.7	40.4	39.2	39.8	40.3	39.3	39.8
Wood fibre slab	40.4	38.2	39.3	40.1	37.6	38.9	40.5	37.9	39.2	41.1	38.1	39.6	40.8	38.1	39.5

Table 5.2.18 Influence of insulation material on heat flow to internal surface of a wall made of double red brick (216 mm) covered on the outside surface by 50 mm mineral wool, polystyrene or wood fibre slabs.

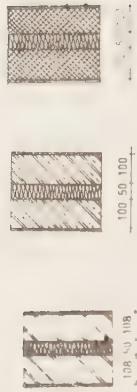
Insulation material	Heat flow (Wh)											
	South			North			West			East		
	Max.	Min.	Max.	Max.	Min.	Max.	Max.	Min.	Max.	Max.	Min.	Max.
 Mineral wool	32.1	7.4	21.3	-4.6	22.3	-44.4	-6.5	-21.8				
 Polystyrene	25.5	1.3	18.5	-7.1	14.9	-32.1	5.6	-23.8				
 Wood fibre	45.2	22.4	28.5	-3.1	37.6	-90.9	12.6	-51.0				

Table 5.2.19 Influence of insulation material on heat flow to internal surfaces of walls made of double brick sandwiched with 50 mm mineral wool, expanded polystyrene or wood fibre.



Insulation material	Heat flow to internal surfaces (Wh)								
	South			North			West		
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Mineral wool slab	36.5	2.6	26.3	-11.1	33.1	-56.9	-6.2	-29.1	
Polystyrene slab	28.5	-0.9	21.7	-9.7	25.8	-40.4	3.4	-22.7	
Wood fibre slab	57.3	16.0	34.6	-9.0	48.4	-99.5	14.2	-46.9	

Table 5.2.20 Influence of different heat capacity of a double wall sandwiched with 50 mm mineral wool on internal surfaces and room air temperature.



Type of wall	Reduction of room air temperature		Reduction of inner surface temperature (°C)													
			South				North				West				East	
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	
double red brick	7.3	-17.0	-4.8	7.5	-16.8	-4.6	7.3	-16.9	-4.8	7.0	-17.0	-5.0	7.1	-17.0	-5.0	
double hollow brick	7.1	-17.0	-4.8	7.2	-16.5	-4.7	7.2	-16.4	-4.8	6.7	-16.5	-5.0	6.9	-16.7	.5.0	
double ord. concrete	7.3	-17.3	-5.1	7.4	-17.2	-4.9	7.2	-17.3	-5.1	7.0	-17.5	-5.3	7.0	-17.5	-5.3	

Reductions of room air temperature and inner surface temperature compared with maximum and minimum outdoor air temperatures (47.2 °C and 21.6 °C respectively).

From the comparison in Table 5.2.21 between a wall made of 216 mm red brick with another made of two 108 mm brick walls with air or mineral wool in the space between, it can be seen that the case of a massive wall of red brick will give a maximum room air temperature of 41.9°C . If the wall has an unventilated air space, the maximum temperature will drop by 0.9°C to 41.0°C and with 50 mm mineral wool in the space the maximum room air temperature will drop another 1.2°C to 39.8°C . The air space has an effect, but putting mineral wool in the space will give a much better effect. Mineral wool in the space instead of air will decrease the maximum room air temperature with 1.3°C for hollow brick walls and with 0.7°C for solid concrete walls. Thus the effect of putting mineral wool in the space is remarkably lower for concrete walls than for brick walls.

5.2.3 Effect of ventilation in cavity walls

If the air in a cavity wall is ventilated, the heat flow through the wall will be considerably reduced. Therefore the effect of ventilated air spaces on indoor temperature has been studied from two aspects:

- 1) influence of ventilation conditions of the cavity on indoor temperature
- 2) influence of different wall properties (thickness, thermal capacity, thermal resistance)

The effect of a cavity wall on indoor temperature has been studied in model (1): 4.0 m wide, 5.0 m long and 2.8 m high, with a shaded window 1.2 m^2 in the northern facade (no direct radiation but 80% of the diffuse radiation). The roof and floor are the same as in model (1), (Figure 5.1.1), the wall cavity is assumed equal to 50 mm air space.

In order to simplify the identification of the cases, these are denoted by codes. The first position indicates the type and thickness of the external layer of the cavity. The second position (-) indicates the air space of 50 mm. The third position indicates the type and thickness (in cm) of the internal layer of the cavity, with following code:

Table 5.2.21 Influence on room air temperature of a space with air or mineral wool in a double brick wall.

Time of day	Room air temperature ($^{\circ}\text{C}$)							
	Red brick		Hollow brick		Concrete			
	Massive wall no space	Air in space	Min wool in space	Air in space	Min wool in space	Air in space	Min wool in space	
h								
01.00	40.1	40.2	39.5	40.2	39.7	40.1	39.7	
02.00	39.5	39.9	39.4	39.8	39.5	39.8	39.6	
03.00	38.9	39.5	39.3	39.3	39.3	39.5	39.5	
04.00	38.3	39.0	39.1	38.8	39.1	39.2	39.4	
05.00	37.8	38.7	39.0	38.5	38.9	38.8	39.3	
06.00	37.3	38.4	38.2	38.2	38.7	38.6	39.3	
07.00	37.1	38.2	38.8	37.7	38.4	38.1	39.1	
08.00	36.8	37.9	38.6	37.7	38.4	38.1	39.1	
09.00	36.9	37.8	38.5	37.6	38.3	38.1	39.0	
10.00	36.6	37.8	38.5	37.7	38.3	38.1	38.9	
11.00	37.5	37.9	38.5	37.9	38.3	38.1	39.0	
12.00	37.9	38.2	38.6	38.2	38.4	38.3	39.1	
13.00	38.5	38.5	38.8	38.6	38.6	38.5	39.2	
14.00	39.0	38.8	39.0	39.0	38.8	38.8	39.3	
15.00	39.7	39.2	39.1	39.4	39.0	39.0	39.4	
16.00	40.2	39.6	39.3	39.8	39.2	39.4	39.5	
17.00	40.7	40.0	39.4	40.4	39.4	39.6	39.6	
18.00	41.3	40.3	39.5	40.7	39.6	40.0	39.7	
19.00	41.7	40.7	39.6	41.1	39.8	41.2	39.8	
20.00	41.9	40.8	39.7	41.2	39.9	40.4	39.8	
21.00	41.9	41.0	39.7	41.3	40.0	40.6	39.9	
22.00	41.8	40.9	39.8	41.2	40.0	40.5	39.9	
23.00	41.3	40.8	39.7	41.0	40.0	40.5	39.8	
24.00	40.8	40.5	39.7	40.6	39.9	40.3	39.7	

H = hollow brick
 S = limestone
 B = red brick
 C = ordinary concrete
 M = mineral wool

The fourth position indicates the condition of cavity ventilation

U = unventilated
 P = permanent ventilation
 N = night ventilation (between 1900 and 0800)

The ventilation of the cavity is normally assumed to be $112 \text{ m}^3/\text{h}$ per meter wall (800 airchanges/h) which presumes an air velocity of 0.6 m/s .

This velocity cannot be obtained by natural ventilation (stack effect). Mechanical equipment must be used.

The fifth position indicates the condition of room ventilation.

U = unventilated
 P = permanent ventilation
 N = night ventilation (between 1900 and 0800)

The sixth position indicates the colour of the outside surface

G = grey
 B = black
 W = white

Example: H10-S20PUG

This means that the cavity wall is made of 10 cm hollow brick outside layer, air space 50 mm and 20 cm limestone as internal layer. The cavity has permanent ventilation, the room is unventilated and the outside surface is grey.

Influence of ventilation conditions of the cavity

The influence of ventilation of cavity was studied with the room unventilated and the cavity unventilated, permanently ventilated and night-ventilated. It can be seen from Figure 5.2.18 that when the cavity is unventilated, maximum room air temperature will be lower than maximum outdoor temperature by 6.5°C , from 47.2°C to 40.7°C . When the cavity is permanently ventilated, the temperature will be 39.4°C and when the cavity is ventilated at night only, the temperature will decrease to 37.2°C .

Ventilation of the cavity will also reduce the minimum room air temperature. When the cavity is unventilated, the minimum room air temperature will be 38.3°C . In the case of permanent ventilation the minimum temperature will be 34.7°C . When the cavity is ventilated at

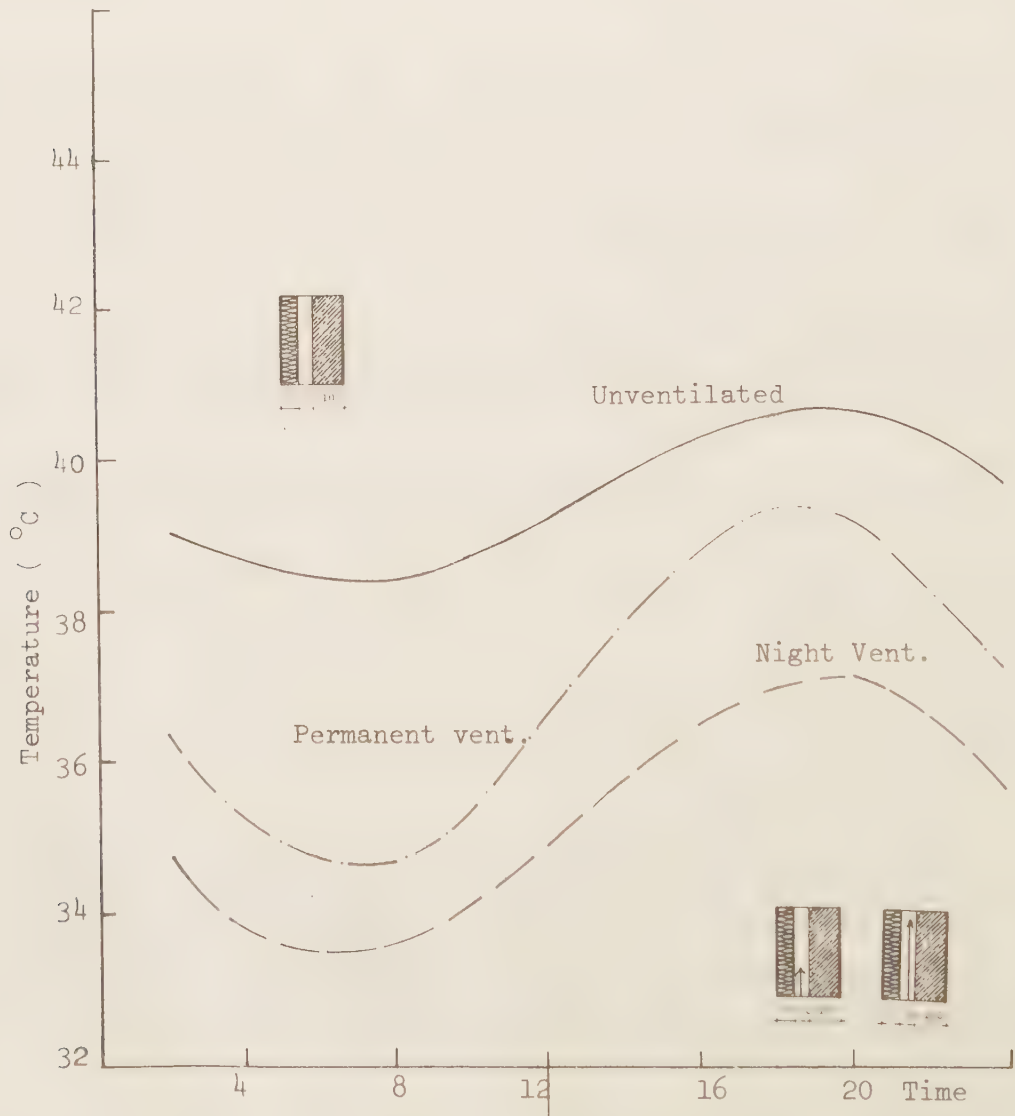


Figure 5.2.18 Influence of ventilating the cavity on room air temperature. Comparison between case M5-S10UUG, M5-S10PUG and M5-S10NUG.

night, the minimum temperature will be 33.5°C .

As seen from Figure 5.2.18, night ventilation of the cavity has a very large effect on the room air temperature compared with an unventilated cavity. The temperature reduction is about 4°C .

The temperatures of the walls on both sides of the cavity are shown in Table 5.2.22 for unventilated, permanently ventilated and night ventilated cavities. In Figures 5.2.19 - 5.2.21 the heat flows to/from the surfaces are shown for unventilated, permanently ventilated and night-ventilated cavities. The wall has 50 mm mineral wool outside the cavity and 100 mm limestone on the inside. It can be seen that a night-ventilated wall has a heat flow to its inside surface day and night but a permanently ventilated wall gives heat to the room evenings only.

Influence of wall properties

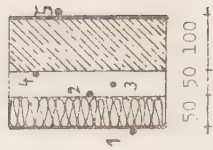
In Figures 5.2.22 - 5.2.24 and Table 5.2.23 a number of combinations of external and internal walls are gathered. The figures show the variation of the room air temperature day and night for permanently ventilated cavities. It can be seen that thick walls decrease the temperature swing of the room air and that it is better to have the thermal capacity inside the cavity.

Tables 5.2.24 - 5.2.25 show similar results for night-ventilated cavities. Table 5.2.24 indicates that the best result is obtained with 50 mm mineral wool outside the cavity and 100 mm concrete on the inside (alternative 3). If the room is also night-ventilated it is possible to limit the maximum room air temperature to 35.3°C for a wall with 50 mm mineral wool on the outside and 300 mm limestone inside the cavity (case M5-S30NN6 in Table 5.2.25). Figure 5.2.25 also shows some wall combinations which confirm the above-mentioned results.

Light, insulated materials outside the wall will of course result in high outer surface temperatures. Figure 5.2.26 shows that 70°C can be obtained on a mineral wool wall facing west. Concrete reduces the maximum surface temperature with approximately 10°C .

Table 5.2.22 Comparison between cavity walls facing west in case of unventilated, permanently ventilated and night-ventilated cavity with 800 airchanges per hour.

Time of day h	Out-door air temp	Unventilated					Permanent ventilated					Night ventilated				
		temperature point					temperature point					temperature point				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
01.00	22.0	23.1	37.3	38.3	39.3	40.1	22.6	29.6	24.4	33.0	36.8	22.6	28.9	24.1	31.9	35.3
02.00	21.5	22.6	36.7	37.8	38.8	39.8	22.2	28.8	23.9	32.2	36.0	22.1	28.1	23.7	31.1	34.6
03.00	22.1	23.0	36.2	37.3	38.4	39.4	22.5	28.4	24.2	31.6	35.3	22.5	27.8	23.9	30.6	33.9
04.00	23.6	24.3	35.8	36.9	38.0	39.1	23.9	28.6	25.3	31.4	34.7	23.8	27.9	25.1	30.5	33.5
05.00	26.0	26.5	35.7	36.8	37.8	38.8	26.0	29.2	27.2	31.5	34.2	25.9	28.6	26.9	30.6	33.0
06.00	29.1	30.4	35.9	36.8	37.6	38.6	30.0	30.4	29.6	31.9	33.9	29.9	29.8	29.4	31.1	32.8
07.00	32.6	34.9	36.5	37.0	37.6	38.4	34.6	32.0	32.5	32.7	33.8	34.5	31.5	32.4	31.9	32.8
08.00	36.2	39.4	37.2	37.5	37.8	38.3	39.1	34.0	35.6	33.7	33.9	39.1	32.3	32.3	32.2	32.9
09.00	39.7	43.5	38.0	38.0	38.1	38.3	43.3	36.1	38.6	34.9	34.3	43.2	33.4	33.1	32.8	33.2
10.00	42.8	47.1	38.9	38.7	38.4	38.4	46.9	38.2	41.3	36.2	34.8	46.8	34.5	33.9	33.4	33.5
11.00	45.2	49.8	39.8	39.3	38.8	38.6	49.8	39.9	43.5	37.4	35.4	49.6	35.6	34.8	34.0	33.8
12.00	46.7	52.6	40.6	39.9	39.3	38.8	52.6	41.4	44.9	38.5	36.2	52.3	36.5	35.6	34.6	34.2
13.00	47.2	59.5	41.4	40.6	39.8	39.1	59.5	42.6	45.7	39.4	36.9	59.2	37.5	36.4	35.3	34.7
14.00	46.8	65.0	42.8	41.7	40.5	39.4	65.1	43.8	45.6	40.3	37.6	64.8	39.1	37.7	36.2	35.1
15.00	45.7	68.4	44.3	42.8	41.3	39.8	68.5	44.8	44.9	40.9	38.3	68.2	40.7	38.9	37.2	35.6
16.00	44.0	68.7	45.5	43.8	47.1	40.2	68.8	45.2	43.8	41.3	38.9	68.5	42.1	40.1	38.1	36.1
17.00	41.7	64.7	46.3	44.5	42.7	40.6	64.7	44.9	42.1	41.4	39.4	64.5	42.5	40.9	38.9	36.7
18.00	38.9	53.8	46.2	44.6	43.0	40.9	53.8	43.8	39.8	41.0	39.7	53.6	42.9	41.1	39.3	37.1
19.00	35.9	37.7	44.8	43.8	42.8	41.2	37.6	41.5	37.2	40.2	39.8	37.5	40.3	36.8	38.3	37.5
20.00	32.9	33.9	42.0	41.9	41.9	41.3	33.8	38.1	34.3	38.8	39.7	33.7	36.9	33.9	37.1	37.6
21.00	29.9	30.9	40.6	40.9	41.3	41.2	30.7	35.8	31.6	37.5	39.3	30.6	34.8	31.3	35.9	37.4
22.00	27.1	28.2	39.6	40.2	40.8	41.0	27.9	33.9	29.2	36.3	38.8	27.8	32.9	28.9	34.9	37.0
23.00	24.8	25.9	38.8	39.5	40.3	40.8	25.6	32.2	27.1	35.1	38.2	25.5	31.4	26.8	33.8	36.5
24.00	32.1	24.2	37.9	38.9	39.8	40.5	23.8	30.8	25.5	33.9	37.5	23.7	29.9	25.2	32.8	35.9



Mineral wool slab, 50 mm on the outside and 100 mm limestone on the inside. Night ventilation from 1900-0800, unventilated room.

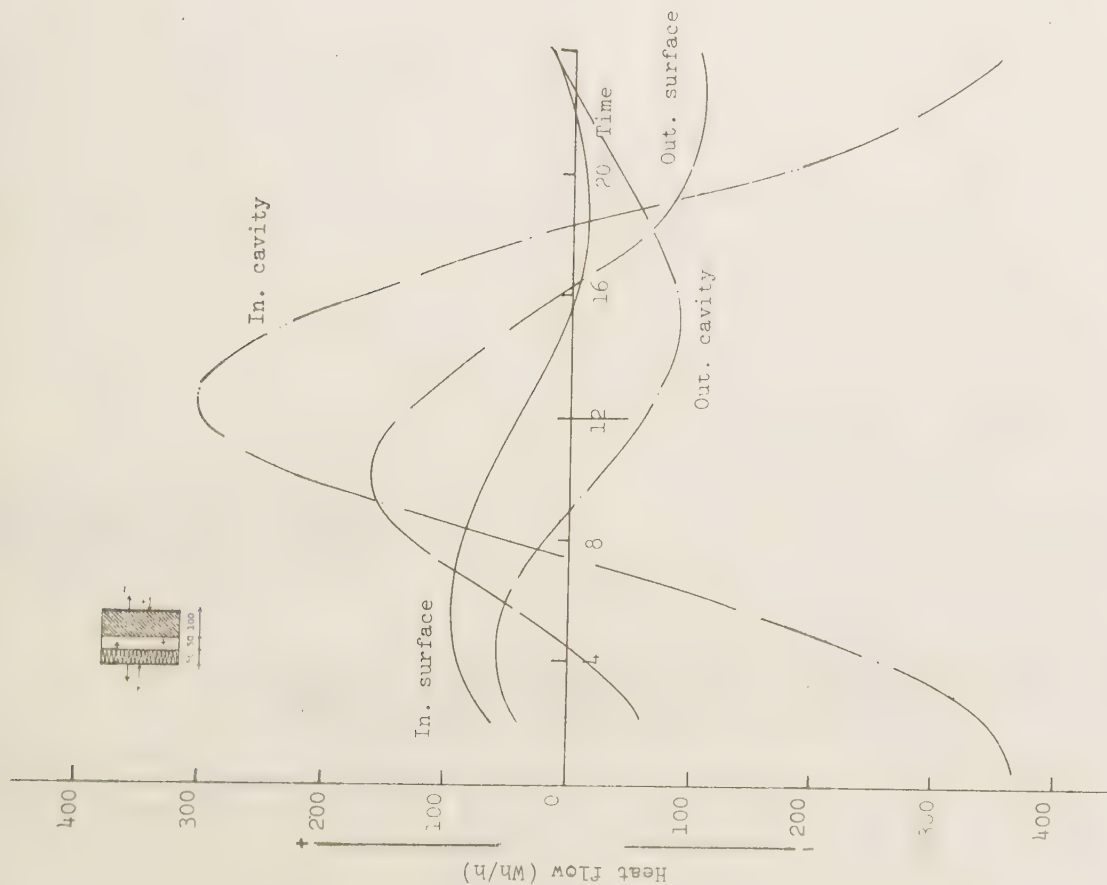


Figure 5.2.19 Heat flow to external and internal surfaces of cavity walls facing south. Case M5-S10UUG.

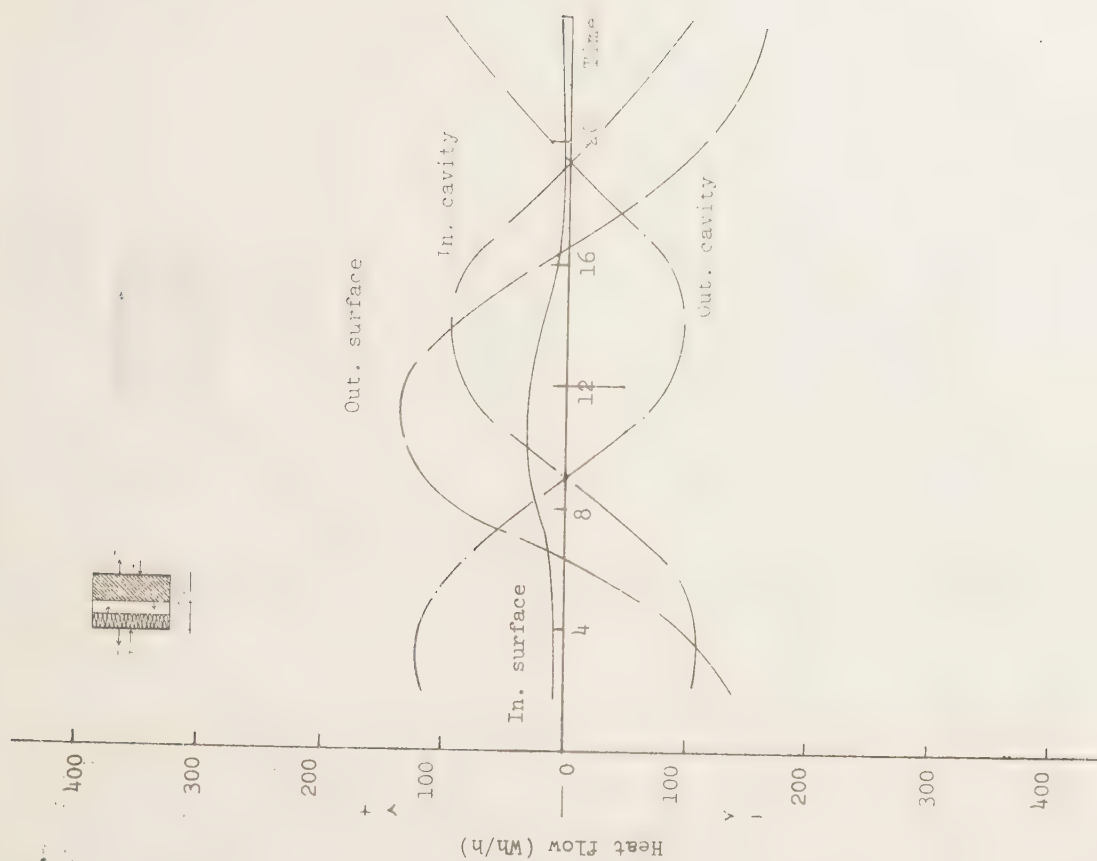


Figure 5.2.20 Heat flows to internal and external surfaces of cavity walls facing south. Case M5-S10PUG.

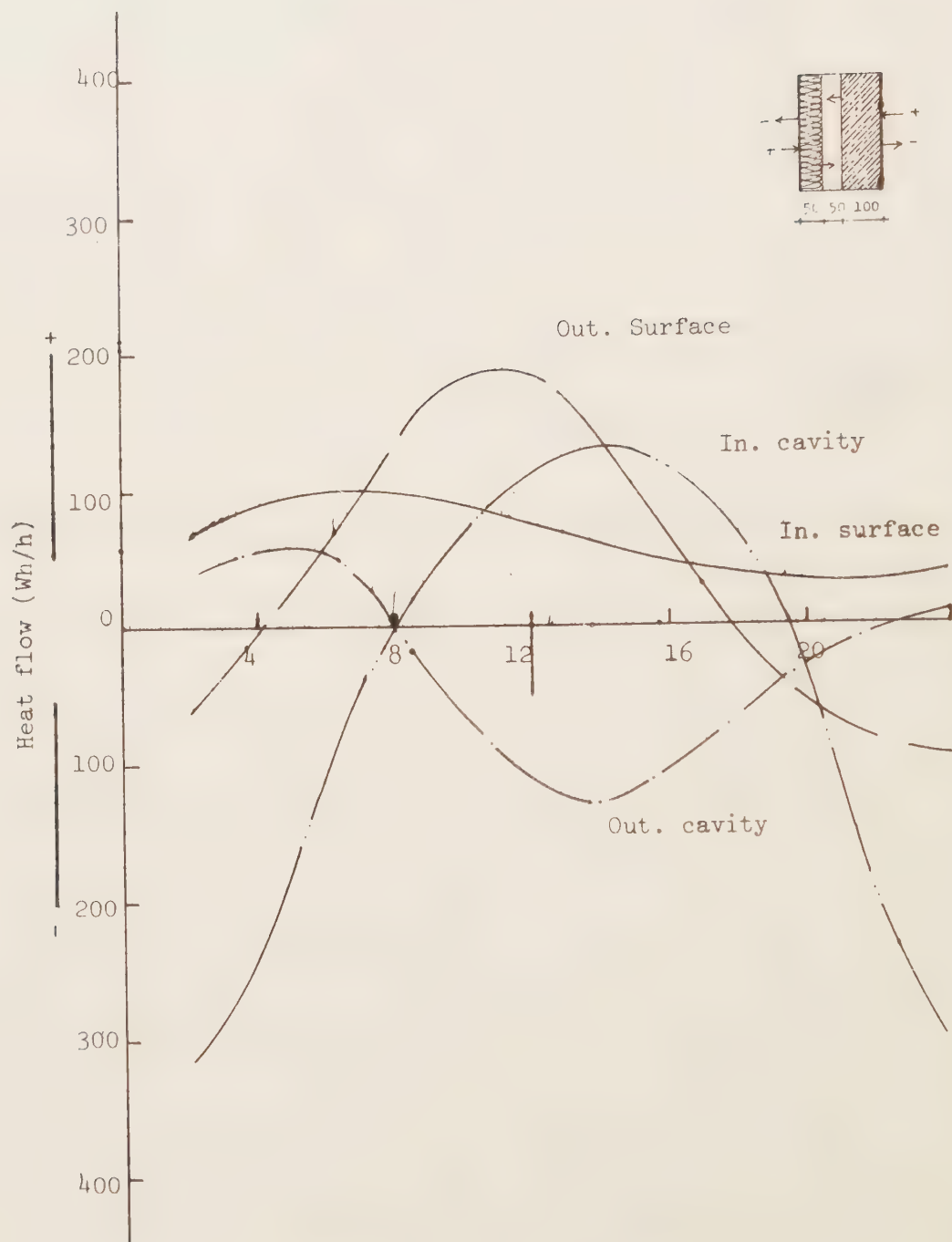


Figure 5.2.21 Heat flow to external and internal surfaces of cavity walls facing south. Case M5-S10NUG.

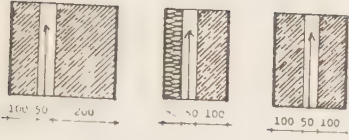


Figure 5.2.22

Influence of different construction of cavity wall on room air temperature.

Comparison between cases S10-S10PUG, S10-S20PUG and M5-S10PUG.

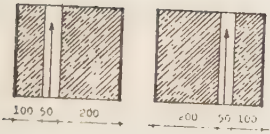
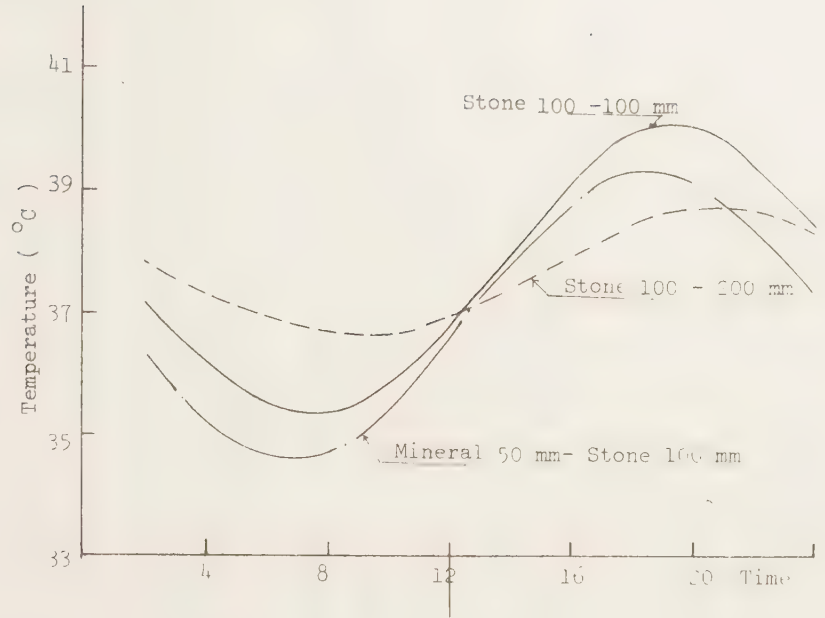


Figure 5.2.23

Influence of different construction of cavity wall on room air temperature.

Comparison between cases S10-S10PUG and S10-S20PUG.

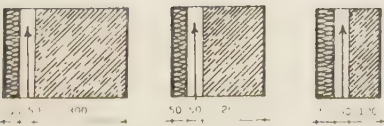
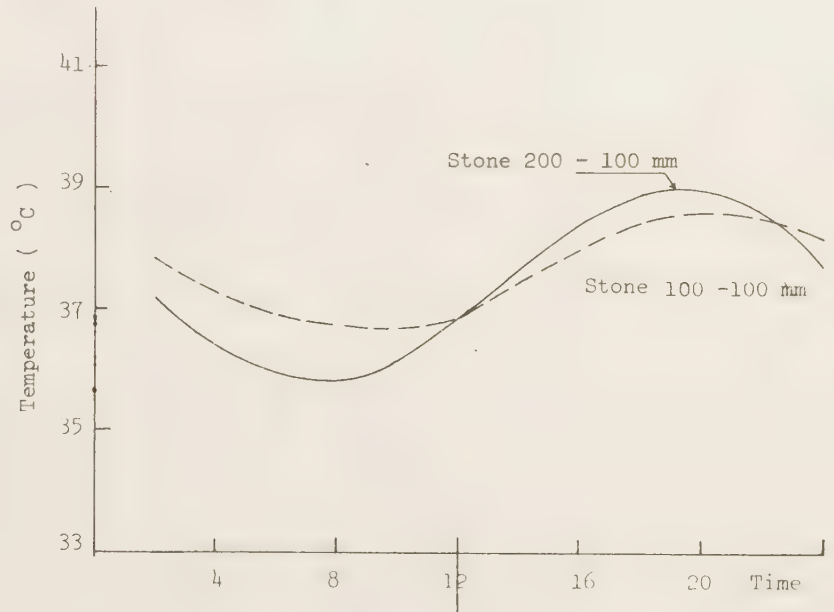


Figure 5.2.24

Influence of thickness of internal layer on room air temperature.

Comparison between cases M5-S10PUG, M5-S20PUG and M5-S30PUG.

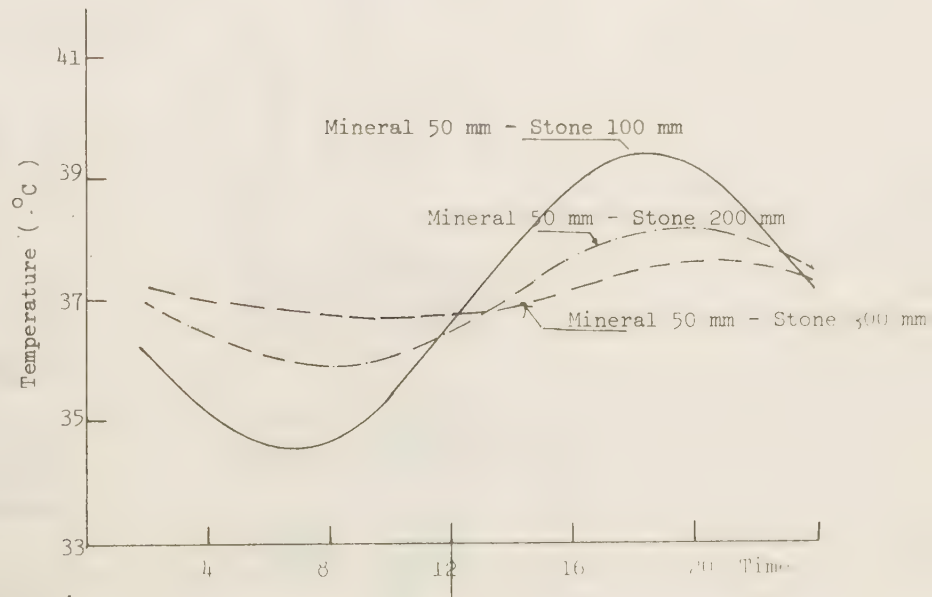
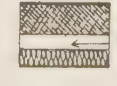
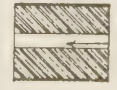


Table 5.2.23 Influence of thickness of internal layer of the cavity on indoor temperature. Outer wall made of 50 mm mineral wool and inner wall of d mm limestone. Permanently ventilated cavity and unventilated room.

Case				d mm	Internal surface temperature (°C)											
					Room air temperature				South				North			
					Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
					Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
M5-S10PUG				100	39.4	34.6	36.9	39.4	33.7	36.6	39.5	33.8	36.7	39.8	33.9	36.8
M5-S20PUG				200	38.2	35.9	37.0	38.1	35.4	36.8	38.2	35.4	36.8	38.3	35.5	36.9
M5-S30PUG				300	37.7	36.7	37.2	37.6	36.3	36.9	37.7	36.3	37.0	37.8	36.5	37.1

Table 5.2.24 Influence of different external and internal layer of the cavity on indoor temperature.
Night-ventilated cavity and unventilated room.

Case	Alt	Room air temperature	Internal surface temperature (°C)												
			South				North				West				East
			Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	
	M5-H10NUG	1	38.0	33.7	35.8	37.7	32.9	35.3	37.9	32.9	35.4	38.4	33.1	35.6	35.6
	M5-S10NUG	2	37.2	33.4	35.3	36.9	32.6	34.7	37.1	32.7	34.8	37.6	32.8	35.0	35.1
	M5-C10NUG	3	36.4	33.6	35.1	35.9	32.9	34.5	36.1	33.0	34.6	36.6	33.2	34.8	34.8
	H10-H10NUG	4	39.1	34.6	36.7	38.8	33.8	36.2	39.1	33.9	36.3	39.7	34.0	36.6	36.7
	S10-S10NUG	5	39.0	34.8	36.8	38.7	33.9	36.2	39.1	34.0	36.4	39.8	34.2	36.7	36.8
	C10-C10NUG	6	37.9	35.3	36.6	37.6	34.6	35.9	37.9	34.7	36.2	38.5	35.0	36.6	36.7

M5 = 50 mm of mineral wool, H10 = 100 mm of hollow brick, S10 = 100 mm of lime stone and C10 = 100 mm of concrete.

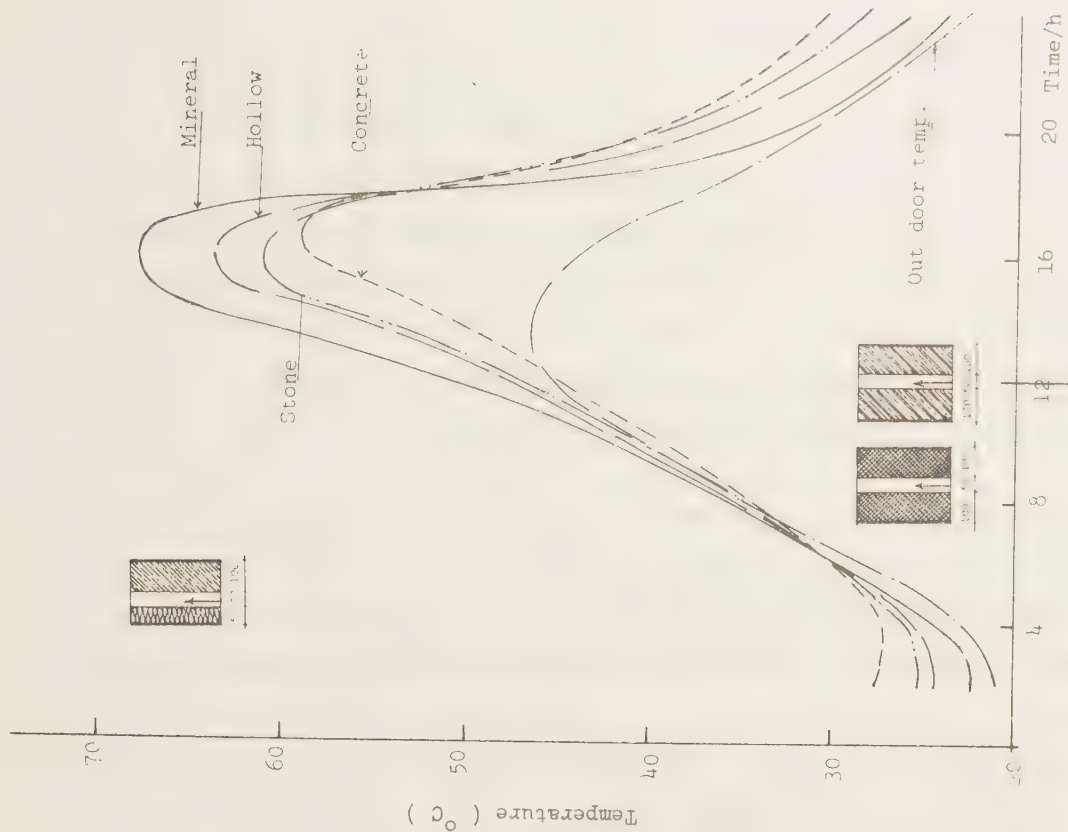


FIG.5.2.26 External surface temperature of cavity walls facing west. Comparison between case: M5-H10NUG, H10-H10NUG, S10-S10NUG and C10-C10NUG.

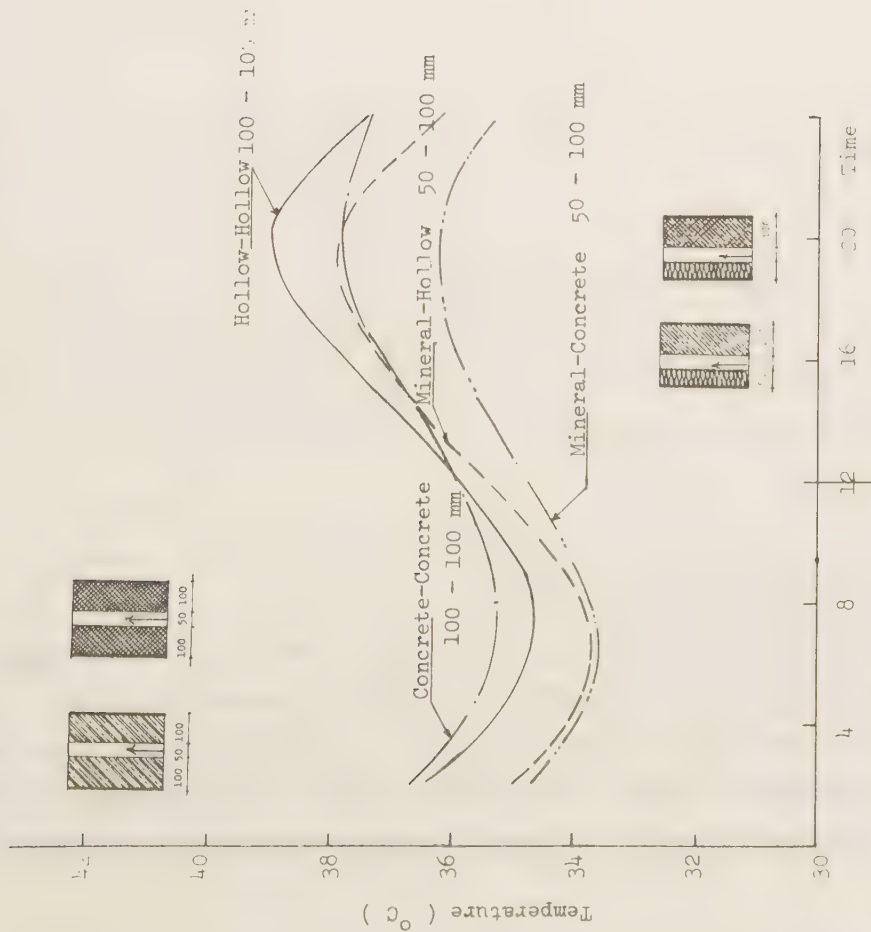


Figure 5.2.25 Influence of different cavity wall construction on room air temperature. Night ventilated cavity. Comparison between cases H10-H10NUG, C10-C10NUG, M5-H10NUG and M5-C10NUG.

5.2.4 Effects of surface characteristics

All material exposed to radiation will absorb radiation energy in a greater or lesser degree, depending on the absorptivity of the exposed surface. One of the most effective defences against solar heat is a selected use of design materials which reflect most of the solar radiation. Most opaque building materials reflect this kind of radiation according to their colour; white reflects a large part of the solar radiation and dark colours only a smaller part.

When the surface of the material is heated by the absorbed solar radiation, part of the heat is transferred into the material and part of it is transferred to the air by convection and to surrounding surfaces by long wave radiation. The heat balance of the surfaces depends therefore on

- reflection of solar radiation
- thermal properties of the material behind the surface
- air temperature and the convection heat transfer coefficient
- temperature and position of surrounding surfaces and the emissivities of the actual surface and surrounding surfaces

During clear nights the sky has a very low temperature and the night radiation from roofs is considerable. It has been used for natural cooling of buildings.

In this study various exterior materials and colours have been examined for a hot, arid climate. The discussion in this section concerns a) the influence of external surfaces on indoor temperature, b) the influence of shading external surfaces on indoor temperature.

a) Influence of external colour

White finishes on the external surfaces of walls are not always appreciated, especially in arid lands. Dust storms frequently cause the white colour to become dirty or yellow, white colour can also cause unpleasant glare. This study concerns the influence of different external colours on external and internal surface temperatures and room air temperature,

with respect to the heat capacity and thermal resistance of the wall and the ventilation condition of the room.

The absorption coefficient of the wall is assumed to be for white 0.3, for grey 0.5 and for black 0.8, which means that the white colour is not extremely reflecting.

Results for external surface temperatures with different wall types are summarized in Table 5.2.26. It is seen that the highest temperature of the outside surface occurs when the external colour is black and the lowest when it is relatively white. Comparing the different orientations, it is seen that when the wall is made of 100 mm hollow brick ("high" thermal resistance) and facing south, the difference in maximum surface temperature between grey and white is 3.1°C and between grey and black about 2.2°C . In a westerly direction, maximum outside surface temperature in the case of white will be about 22°C lower than when the surface is black. It can also be noted that the difference for minimum outside surface temperature with different colours and orientation is significant.

In the case of a concrete wall (high thermal capacity) with a south orientation, the maximum external surface temperature with white will be 4.7°C lower than the surface temperature with black colour, but a west wall gives a decrease of 18°C . Thus dark colours have a great effect on the external surface temperature on a western surface but not on a southern surface. Therefore the colour for south and north facades can be chosen without restrictions, but on east and west facades it is preferable to choose light colours or to treat the wall surface against solar radiation.

Concerning the effect of external colour on room air temperature, it will be seen from Figure 5.2.27 that a white external surface gives lower daily mean temperature of room air than black surfaces. Also it can be seen that the daily swing of the room air temperature is dependent on the external colour, but to a larger degree on the thickness of the wall. Table 5.2.27 also shows that, when the wall is made of 100 mm hollow brick facing south and coloured black, the maximum inside surface temperature will be 0.5°C above maximum outdoor air tem-

Table 5.2.26 Influence of external colour on outside surface temperature, 100 mm thick walls and unventilated room.

Wall mate- rial	External colour	External surface temperature (°C)												
		South			North			West			East			
		Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	
	Red brick	Black	51.3	26.7	38.6	54.4	26.9	41.0	73.6	27.3	44.1	64.4	26.8	43.9
		Grey	48.3	26.3	37.1	49.9	26.4	38.6	61.9	26.7	40.6	53.8	26.4	40.5
		White	46.3	26.0	36.1	47.2	26.1	37.0	54.1	26.3	38.2	47.7	26.1	38.1
	Hollow concrete	Black	52.9	25.2	38.4	55.7	25.3	40.9	77.4	25.5	44.2	68.2	25.2	44.1
		Grey	49.8	24.9	36.9	51.2	25.0	38.6	64.5	25.1	40.6	56.6	24.9	40.5
		White	47.6	24.8	36.0	48.3	24.8	36.9	55.9	24.9	38.2	49.7	24.8	38.2
	Ordinary concrete	Black	50.0	27.9	38.7	53.3	28.3	41.0	70.7	28.9	44.1	61.8	28.2	43.9
		Grey	47.2	27.4	37.2	50.0	27.6	38.6	59.8	28.0	40.5	52.2	27.5	40.4
		White	45.3	27.1	36.2	46.2	27.2	37.0	52.6	27.4	38.2	46.5	27.1	38.1

perature, which is 47.2°C . When the external colour is grey, the maximum inside surface temperature will be 2.4°C lower than the maximum outdoor air temperature, and when the colour is white it will be 3.6°C lower. The minimum inside surface temperature will be 11.6 , 10.7 and 10.1°C above minimum outdoor air temperature, respectively. On a westerly wall, however, when the external colour is black, maximum inside surface temperature will be 6.2°C above maximum outdoor temperature. When the colour is grey it will be 1.3°C above maximum outdoor air temperature and when the colour is white it will be 2.0°C lower than maximum outdoor air temperature.

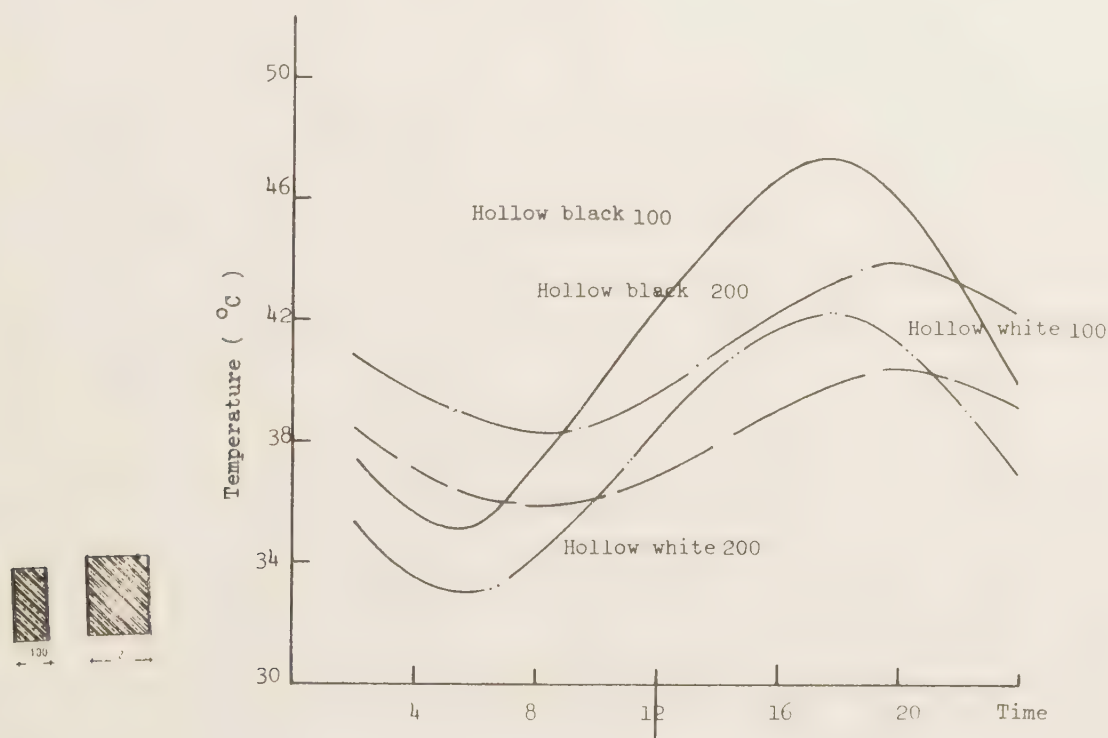


Figure 5.2.27 Influence of thickness and external colour on room air temperature. Walls made of hollow brick 100 and 200 mm thick, painted black and white externally.

When the wall is made of hollow red brick, 200 mm thick, facing south and with black external colour, the maximum inside surface temperature will be 3.5°C lower than maximum outdoor air temperature, compared with 0.5°C above in the case of 100 mm concrete wall. When the external colour is white the maximum inside surface temperature will be 6.9°C lower than the maximum outdoor air temperature, compared with 3.6°C for the 100 mm wall.

Table 5.2.27 Influence of external colour on internal surface temperature and room air temperature. The room is unventilated.

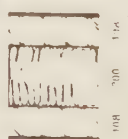
Type of wall and thickness	Ex-ternal colour	Room air temperature		Internal surface temperature (°C)														
				South				North				West				East		
		Max.	Min.	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
	Hollow brick 100 mm	Black	47.9	34.9	41.4	47.7	33.2	40.6	49.2	33.3	41.4	53.4	33.4	42.2	48.4	33.3	42.1	42.1
	Grey	44.7	33.8	39.3	44.8	32.3	38.7	45.8	32.2	39.2	48.5	32.4	39.7	45.3	32.3	39.7	39.7	
	White	42.6	33.1	37.9	43.6	31.7	37.5	43.5	31.7	37.7	45.2	31.8	38.1	43.2	31.7	38.0	38.0	
	Ordinary concrete 100 mm	Black	47.7	35.3	41.7	46.7	33.8	40.4	48.7	33.9	41.5	53.5	34.4	42.7	48.5	33.9	42.6	42.6
	Grey	44.4	34.2	39.3	44.0	32.6	38.4	45.2	32.7	39.1	48.2	33.0	39.9	45.0	32.7	39.8	39.8	
	White	42.3	33.3	37.8	42.1	31.9	37.1	42.9	31.9	37.5	44.7	32.2	37.9	42.7	31.9	37.9	37.9	
	Hollow brick 200 mm	Black	44.1	38.3	41.1	43.7	37.4	40.6	44.5	37.7	41.1	46.1	37.8	41.7	44.7	37.8	41.7	41.7
	Grey	41.8	36.9	39.3	41.6	36.1	38.9	42.1	36.3	39.2	43.2	36.4	39.6	42.3	36.4	39.6	39.6	
	White	40.5	36.1	38.3	40.3	35.4	37.9	40.7	35.5	38.1	41.3	35.5	38.3	40.7	35.6	38.3	38.3	
	Ordinary concrete 200 mm	Black	44.4	38.8	41.6	43.3	37.6	40.5	44.6	38.2	41.4	46.8	38.7	42.4	45.3	38.5	42.4	42.4
	Grey	41.3	36.9	39.0	40.9	35.9	38.5	41.7	36.2	38.9	43.2	36.6	39.6	42.2	36.5	39.6	39.6	
	White	40.1	35.9	37.9	39.6	35.0	37.4	40.1	35.3	37.7	41.0	35.5	38.1	40.4	35.4	38.1	38.1	

This means that if the wall is 100 mm thick with black external colour, white painting is more effective in reducing indoor surface temperatures than increasing the thickness to 200 mm keeping the black external colour. This result is practically independent of wall material. Concerning the room air temperature it is also more effective to change the colour than to increase wall thickness in order to reduce maximum and minimum room air temperature.

In the case of a wall made of double brick sandwiched with insulation, the effects of external colour on indoor temperatures can be seen in Table 5.2.28. The room air and inside surface temperatures are practically independent of the external surface colour when the wall is heavily insulated. The heat flow to the external surface is shown in Figure 5.2.28 for walls made of 100 mm hollow brick and concrete, painted black or white. The largest daily swing occurs for black concrete walls and the lowest for white hollow brick walls. The heat flow to the inside surface is also influenced by external colour when the wall is insulated with mineral wool. Figure 5.2.29 shows the influence for a double wall with 50 mm of mineral wool between the two layers.

In the case of a room ventilated at night with 5 air changes per hour, it can be seen from Table 5.2.29 that when the wall is made of 100 mm stone and the external colour is grey, maximum room air temperature will be 44.7°C . When the external colour is white, the maximum room air temperature is 39.9°C . If the wall is 200 mm thick and the external colour is grey, the maximum room air temperature will be 40.1°C and if it is white 37.5°C . When the wall is 400 mm thick with grey colour, maximum room air temperature will be 37.6°C and with white colour it will be 35.8°C . This means that the maximum room air temperature is the same whether the wall is 200 mm thick and external surface is white or the wall is 400 mm thick and the external surface is grey. Moreover the minimum room air temperature will be lower by 1.9°C in the case of a wall 200 mm thick with white colour than a wall 400 mm thick with grey colour.

Table 5.2.28 Influence of external colour on inside surface temperature and room air temperature. Comparison between wall made of double brick sandwiched with 100 mm mineral wool and another sandwiched with 200 mm mineral wool. Unventilated room.

Thick- ness of insula- tion	External surface colour	Room air temperature	Internal surface temperature (⁰ C)												
			South			North			West		East				
			Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	
 200 mm	White(N,S,W,E)	39.0	38.3	38.6	38.8	38.5	38.6	38.9	38.5	38.7	38.9	38.5	38.7		
	Grey (N,S,W,E)	39.4	38.7	39.0	39.2	38.9	39.0	39.3	38.9	39.1	39.3	39.0	39.2		
	Black(E) White(S,N,W)	39.4	38.6	38.9	39.2	38.8	38.9	39.2	38.8	39.0	39.2	38.9	39.5	39.3	
 100 mm	White(S,N,W,E)	38.9	38.1	38.5	38.8	38.1	38.4	38.9	38.1	38.5	38.9	38.2	38.7		
	Grey (S,N,W,E)	39.5	38.8	39.1	39.4	38.7	39.0	39.5	38.8	39.1	39.7	38.9	39.3	39.3	
	Black(E) White(S,N,W)	39.5	38.6	39.1	39.3	38.6	38.9	39.4	38.6	39.0	39.5	38.7	39.1	39.9	38.9

S=South, N=North, W=West, E=East

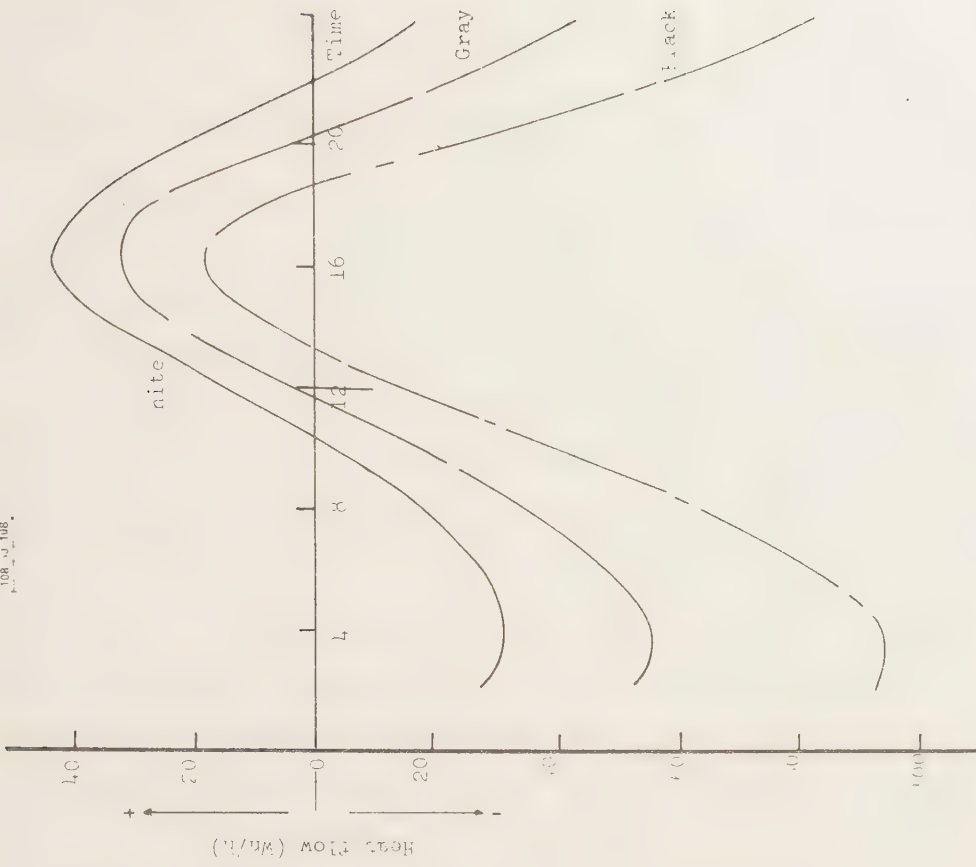


Figure 5.2.29 Influence of external colour on heat flow to inside surface of wall facing west. The wall is made of double brick sandwiched with 50 mm mineral wool.

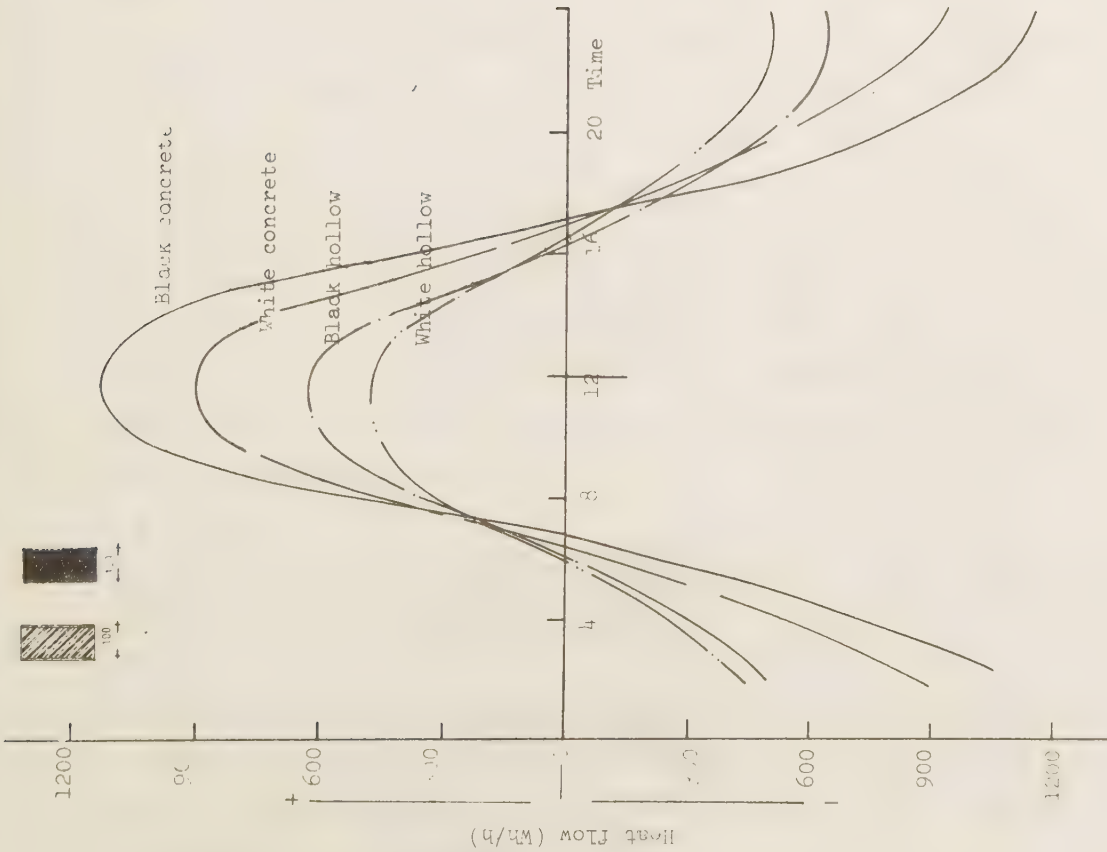


Figure 5.2.28 Influence of external colour on heat flow to outside surface of walls made of 100 mm hollow brick and ordinary concrete.

Table 5.2.29 Influence of external colour on room air and internal surface temperatures for night-ventilated room (5 air changes per hour, 1900-0800)

Walls	Colour	Wall type and thickness	Room air temperature	Inside surface temperature (°C)								
				South		North		West		East		
				Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
	Grey	Stone 100 mm	44.7	29.2	44.7	30.0	45.9	30.1	49.2	30.2	45.3	30.1
		Stone 200 mm	40.1	31.5	40.5	33.7	41.1	33.9	42.5	34.1	41.6	33.9
		Stone 400 mm	37.6	31.9	37.1	35.9	37.4	36.3	37.6	36.7	37.9	36.5
	White	Stone 100 mm	39.9	28.2	40.9	29.1	40.9	29.1	41.0	29.1	40.9	29.1
		Stone 200 mm	37.5	30.0	37.8	32.2	37.8	32.2	37.9	32.2	37.8	32.2
		Stone 400 mm	35.8	30.4	35.3	34.2	35.3	34.2	35.3	34.2	35.3	34.2

b) Effect of external shading

It is evident that light colours reflect most of the incident solar radiation on external surfaces. But this can lead the architect to make all houses the same colour. The alternative is to shade external surfaces. By shading external surfaces, the architect is given more freedom to choose different colours and differ the design of the facade through different shading devices. Shading of the structure will intercept virtually all or most of the solar radiation and decrease the heat flow from the outside.

This part will show the effect of shading of external surfaces on indoor temperature. Shading a wall means reducing direct solar radiation according to the shape and dimension of the shading device. Diffuse radiation is assumed to be reduced by 50% from total diffuse radiation.

Figure 5.2.30 shows a comparison between two cases. In the first, the wall is made of 200 mm limestone with the outer surface shaded; the other wall is 800 mm thick and unshaded. By comparing the walls facing west, it is seen that the shaded wall 200 mm thick gives the same maximum inside surface temperature as the wall 800 mm thick without shading. Even more - the wall 200 mm thick does not store heat as does that 800 mm thick; consequently it cools easily during the night.

A shaded wall is prevented from absorbing radiation and the ambient air temperature has a greater effect than the radiation. Figure 5.2.31 shows that when the outside surfaces of walls are exposed to solar radiation, the highest surface temperature on a west surface will reach about 62 °C, a south surface will reach about 58 °C. When all surfaces are shaded, the maximum temperature for all surfaces will be close to maximum outdoor temperature.

Obviously treatment of external surfaces with light colour or shading affects the indoor temperature, but the question is how the treatment should be designed for different orientations. Figure 5.2.32 shows a comparison between the room air temperature of three models with limestone walls of 100, 200 and 400 mm respectively. External surfaces are either shaded at all surfaces, shaded only at east and west surfaces or unshaded at all surfaces.

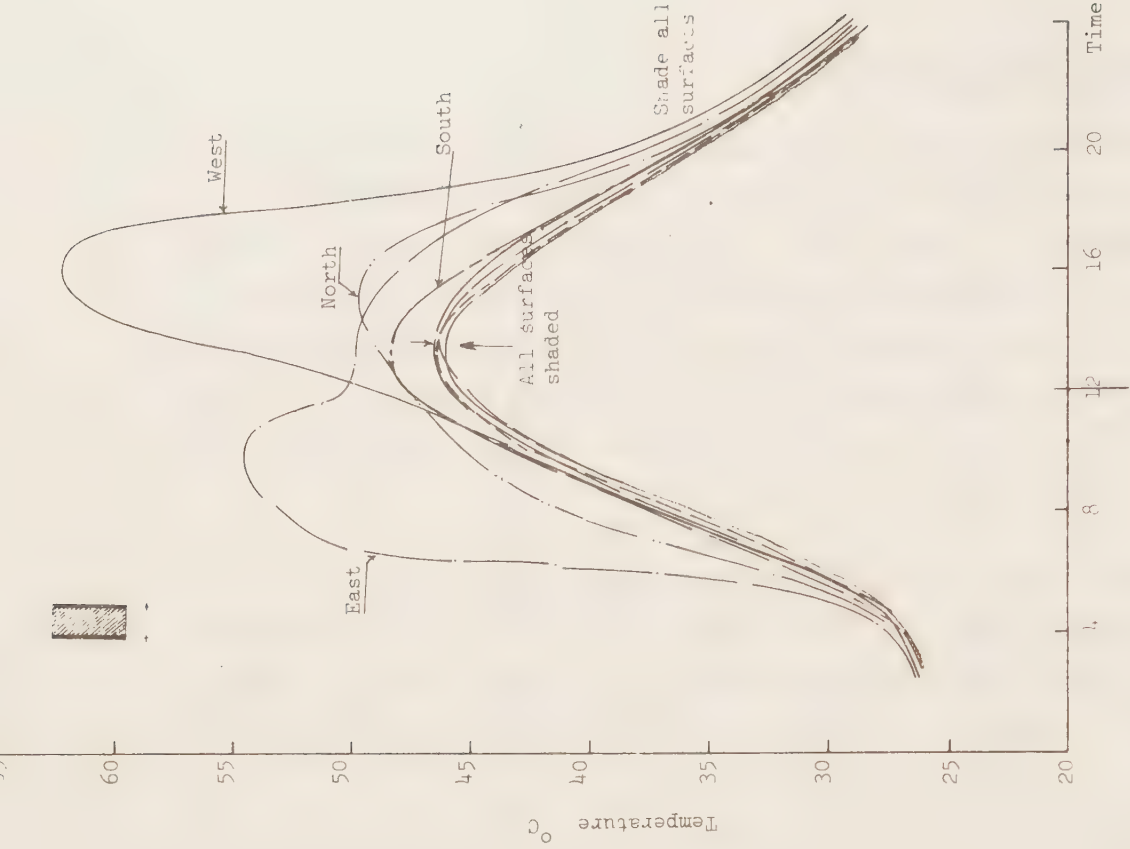


Figure 5.2.31 External surface temperature of wall made of 400 mm limestone in case of shaded and unshaded surfaces.

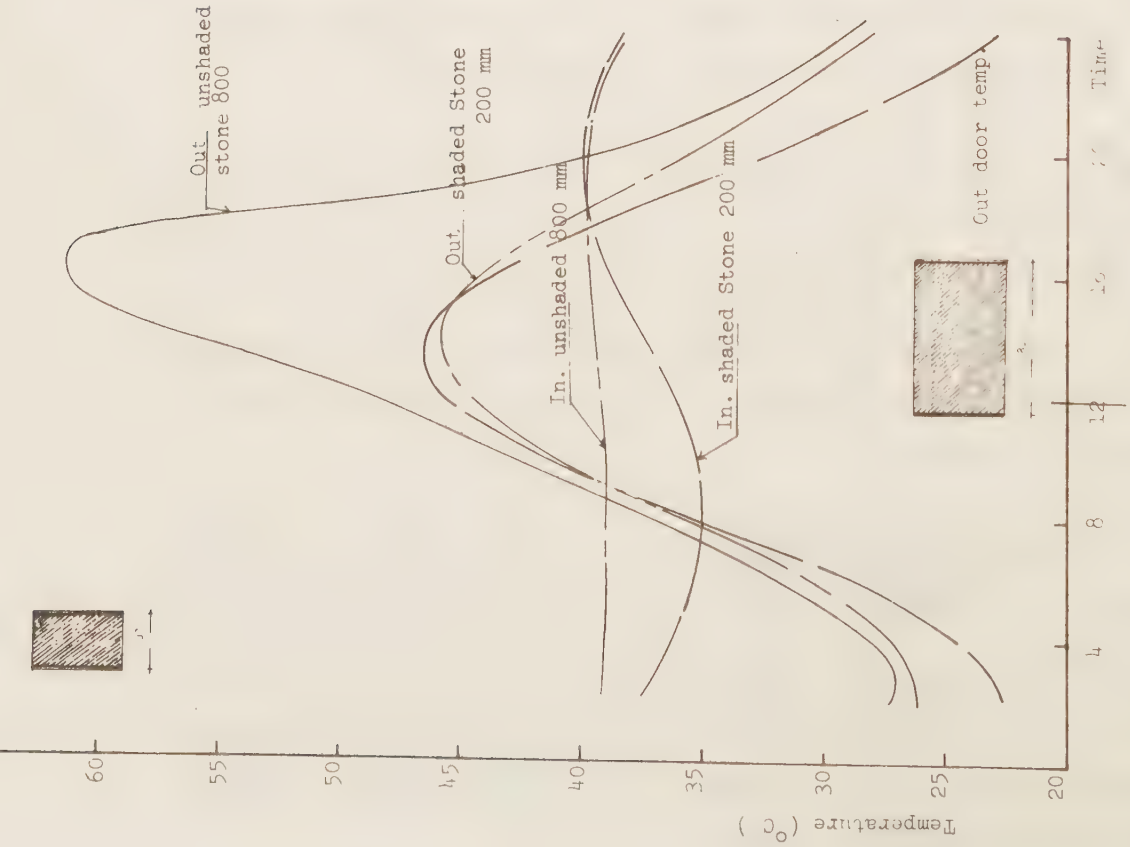


Figure 5.2.30 External and internal surface temperatures of wall facing west. Comparison between wall made of 800 mm limestone, unshaded and 200 mm limestone, shaded.

When the wall is 100 mm thick with shaded east and west surfaces the maximum and minimum room air temperatures will be lower than maximum and minimum room air temperature of a model which has all surfaces unshaded, by 3.5 and 1.0 °C, respectively. When all surfaces are shaded the reduction will be 4.3 and 1.3 °C, respectively.

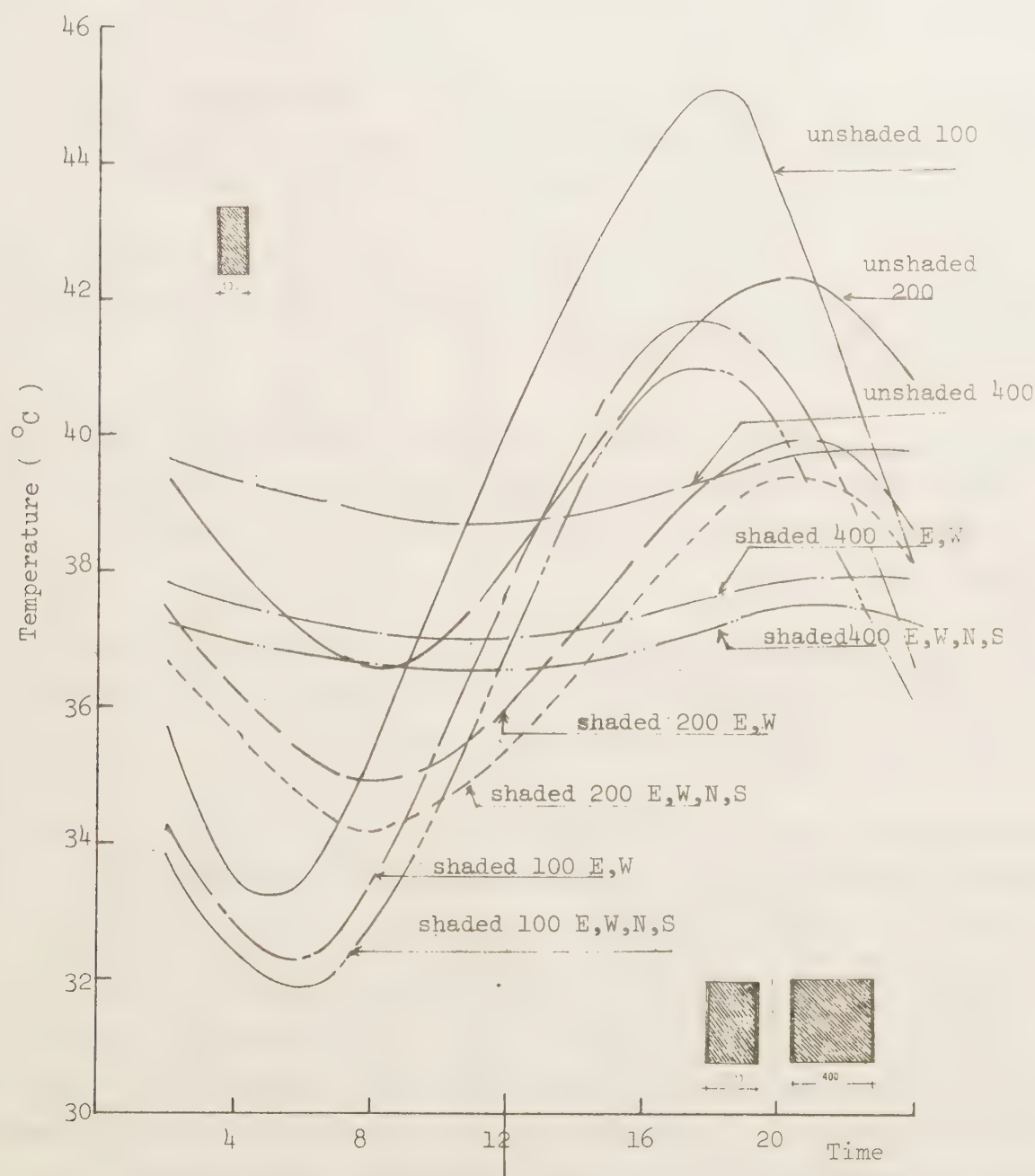


Figure 5.2.32 Influence of thickness and external shading of walls on room air temperature. Comparison between walls, 100, 200 and 400 mm thick, unshaded, shaded in the four cardinal directions and shaded in the east and west only.

When the wall is 400 mm thick with shaded east and west surfaces the maximum and minimum room air temperatures will be lower than maximum and minimum room air temperature of a model which has all surfaces unshaded, by 1.9 and 1.7 °C respectively. In the case of all surfaces shaded, the reduction will be 2.4 °C in maximum and 2.1 °C in minimum room air temperature.

It can also be seen that the 200 mm thick wall with shaded east and west surfaces will give a maximum room air temperature which is about the same as with a 400 mm thick wall with all surfaces unshaded.

Moreover, the minimum room air temperature for the case with 200 mm thick walls will be 4.9 °C lower than the minimum room air temperature of the model with 400 mm thick wall.

When the wall is 100 mm thick with shaded east and west surfaces the maximum room air temperature will be about the same as the maximum room air temperature of a room with 200 mm thick walls and all surfaces unshaded.

This means that shading of the east and west surfaces only can permit reduction of wall thickness to half of the unshaded wall. In addition thin walls can be cooled rapidly during nights.

Since white is not liked in hot arid countries, it is possible to use darker colours but shade the surface by any device. The results are summarized in Table 5.2.30, which shows a comparison between a room with all surfaces painted grey and unshaded (first model) and a room painted black and shaded on its eastern and western surfaces (second model). It can be seen that when the room's surfaces are painted black and the eastern and western surfaces are shaded, maximum room air temperature will be 2.2 °C lower than in the room with all surfaces painted grey and unshaded. The difference of the maximum temperature for the western surface is 5.4 °C. This means that using a dark colour on the external surfaces and shading them is better than using a grey colour which is not shaded. The lowest room air temperature is of course obtained by shading and white painting of all external surfaces (fourth model).

Table 5.2.30 Influence of external shading and colour on room air and internal surface temperatures for an unventilated room. Comparison between four identical models, the first model unshaded and with grey colour on all surfaces, the second shaded only east and west and all surfaces black, the third shaded only east and west and with grey colour on all surfaces, the fourth shaded east and west and with white colour on all surfaces.



Model	Room air temperature			Internal surface temperature (°C)											
				South				North				West			
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Max.	Min.	Mean	Max.	Max.	Min.	Mean	Max.
First model	44.9	33.7	39.3	44.6	32.1	38.5	45.8	32.2	39.1	48.8	32.4	39.8	45.4	32.2	39.8
Second model	42.7	33.0	37.9	44.2	31.6	38.0	45.8	31.7	38.9	43.4	31.6	37.6	43.2	31.6	37.6
Third model	41.6	32.6	37.2	42.6	31.1	37.1	43.7	31.3	37.6	42.4	31.3	36.9	42.0	31.2	36.9
Fourth model	40.6	32.3	36.5	41.5	30.9	36.3	42.1	30.9	36.7	41.2	30.9	36.2	41.1	30.9	36.2

Wall made of 108 mm red brick.

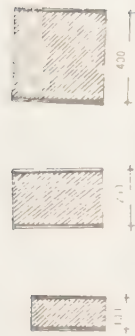
When the external surfaces are shaded it is possible to decrease the maximum room air temperature and night ventilation can reduce the minimum room air temperature as shown in Table 5.2.31.

From the discussion above the following conclusions can be drawn: Treatment of outside surfaces with white colour or with shading devices will reduce the absorption of the wall surfaces and consequently minimize the influence of solar radiation. This will reduce both the maximum and minimum surface temperatures. Increasing the thermal capacity and resistance of the wall will also decrease the maximum and increase the minimum room air temperature. Light colour or shading outside surfaces is however more preferable in hot, arid climates than increasing the thickness of the wall in order to reduce indoor temperature, both from the standpoint of economy and resource conservation.

In old traditional building plans, the house are built very close together, shading each other. On the second floor, where sleeping rooms are located, the walls are very thin and gave low room temperatures at night. At the same time, narrow streets permit people to walk in the shade during summer days.

Table 5.2.31 Influence of external shading of all surfaces in case of night ventilation with 5 air changes per hour on room air and inside surface temperatures. Limestone walls 100, 200 and 400 mm thick. Compare with table 5.2.7

Time of day	Out-door temp	Indoor temperature (°C)											
		Room air			South surface			West surface					
		100 mm	200 mm	400 mm	100 mm	200 mm	400 mm	100 mm	200 mm	400 mm	100 mm	200 mm	400 mm
h	°C												
01.00	21.9	29.3	30.8	30.5	32.1	34.9	34.5	32.1	34.9	34.5	32.1	34.9	34.5
02.00	21.6	28.5	30.3	30.3	30.9	34.2	34.3	30.9	34.2	34.4	30.9	34.2	34.4
03.00	22.1	28.1	30.0	30.4	29.9	33.5	34.2	29.9	33.5	34.2	29.9	33.5	34.2
04.00	23.6	28.2	30.1	30.7	29.3	33.0	34.2	29.3	33.0	34.2	29.3	33.0	34.2
05.00	26.0	28.9	30.7	31.4	29.0	32.6	34.2	29.0	32.6	34.2	29.0	32.6	34.2
06.00	29.0	30.0	31.4	32.4	29.2	32.3	34.3	29.2	32.3	34.3	29.2	32.3	34.3
07.00	32.5	31.5	32.7	33.6	29.8	32.2	34.4	29.9	32.2	34.4	29.9	32.2	34.4
08.00	36.2	31.5	32.9	34.5	30.6	32.1	34.4	30.6	32.2	34.4	30.6	32.2	34.4
09.00	39.7	32.5	33.0	34.5	31.8	32.2	34.4	31.8	32.2	34.4	31.8	32.2	34.4
10.00	42.7	33.6	33.2	34.6	33.2	32.5	34.3	33.2	32.5	34.3	33.2	32.5	34.3
11.00	45.1	34.8	33.5	34.6	34.7	32.9	34.3	34.7	32.9	34.3	34.7	32.9	34.3
12.00	46.6	35.9	34.0	34.7	36.3	33.5	34.2	36.3	33.5	34.3	36.3	33.5	34.3
13.00	47.2	37.0	34.6	34.8	37.7	34.2	34.3	37.7	34.2	34.3	37.7	34.2	34.3
14.00	46.8	38.0	35.3	34.9	39.0	34.9	34.3	39.0	35.0	34.4	39.0	35.0	34.4
15.00	45.7	38.9	36.0	34.9	40.0	35.7	34.5	40.0	35.7	34.5	40.0	35.7	34.5
16.00	43.9	39.5	36.6	35.1	40.6	36.4	34.6	40.6	36.4	34.7	40.6	36.4	34.7
17.00	41.6	39.9	37.1	35.3	40.9	37.0	34.8	41.0	37.1	34.8	41.0	37.1	34.8
18.00	38.9	39.9	37.5	35.5	40.8	37.5	35.0	40.9	37.6	35.0	40.9	37.6	35.0
19.00	35.9	38.3	36.8	35.7	40.1	37.7	35.2	40.2	37.8	35.3	40.2	37.8	35.3
20.00	32.8	36.6	35.7	34.4	39.1	37.6	35.2	39.2	37.7	35.3	39.2	37.7	35.3
21.00	29.8	35.0	34.6	33.4	37.9	37.3	35.2	37.9	37.4	35.2	37.9	37.4	35.2
22.00	27.1	33.4	33.5	32.4	36.5	36.9	35.0	36.5	36.9	35.0	36.5	36.9	35.0
23.00	24.8	31.8	32.5	31.6	35.0	36.3	34.9	35.0	36.3	34.9	35.0	36.3	34.9
24.00	23.0	30.5	31.6	31.0	33.5	35.6	34.7	33.5	35.6	34.7	33.5	35.6	34.7



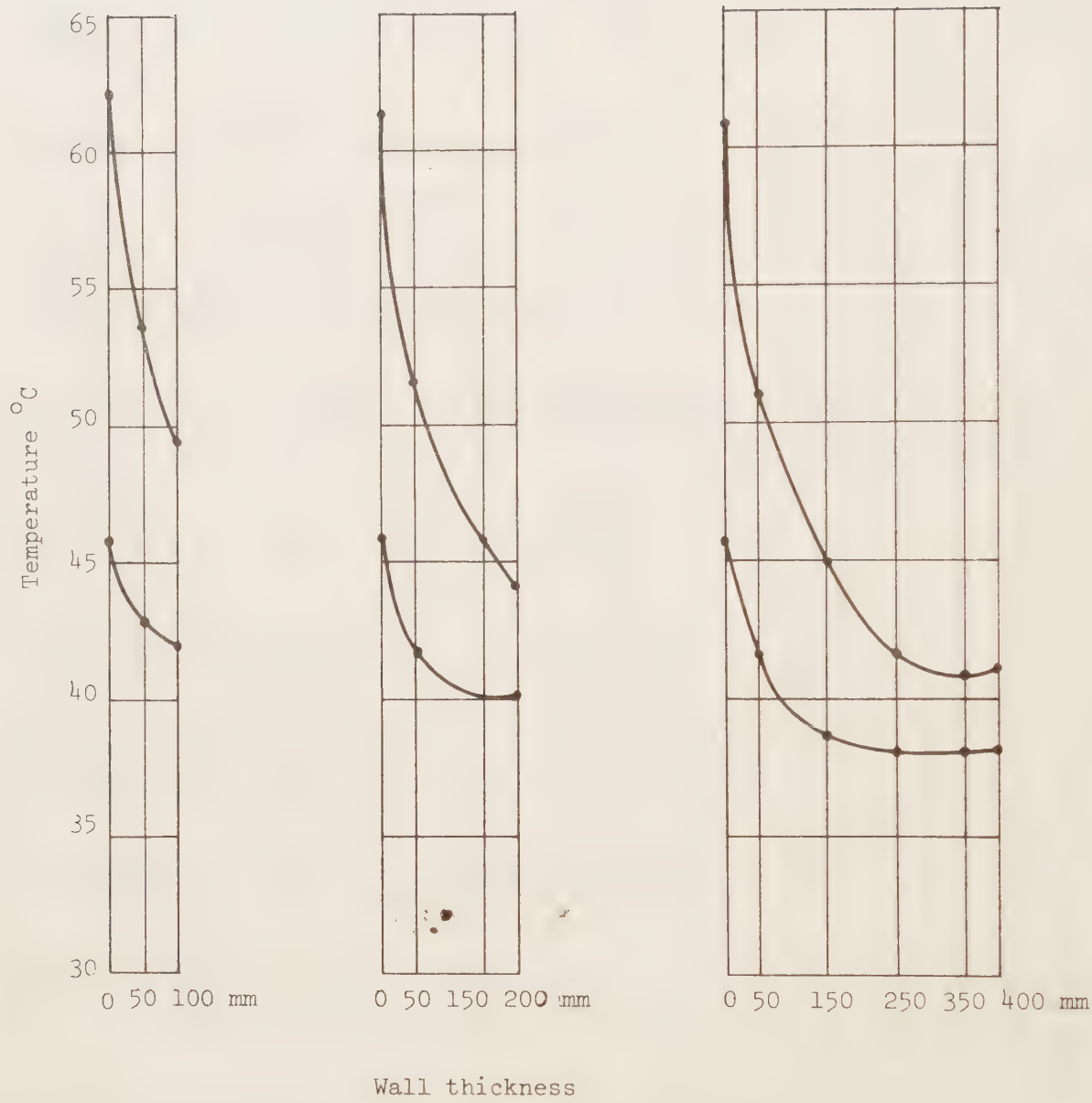


Figure 5.2.33 Influence of external shading on maximum external, inner and internal surface temperatures of walls facing west in different thicknesses.

5.3 INFLUENCE OF ROOF ON INDOOR TEMPERATURE

A flat roof is a major source of heat gain during the daytime and of heat loss by long-wave radiation at night. The roof can be considered in the same way as the wall construction, the only difference being that the quantity of solar incidence on the horizontal surface is much larger than on a vertical surface. In this section, three aspects of the roof will be studied:

- 1) influence of the thermal capacity of the roof
- 2) influence of the thermal insulation of the roof
- 3) the influence of the external colour of the roof on indoor temperature

The thermal network and design alternative of the roof construction are shown in Figure 5.3.1.

During this study of the influence of the roof on indoor temperature, model (1) has been used (see section 5.1). The wall is considered to be made of limestone, 400 mm thick.

5.3.1 Influence of thermal capacity of the roof on indoor temperature

In Egypt, roofs are usually flat and made of solid or hollow concrete slabs. In Table 5.3.1, which shows a comparison between a roof of solid concrete 100 mm thick and another made of hollow concrete slab 280 mm thick, it can be seen that in the first instance the maximum room air temperature will be 7.2°C lower than maximum outdoor temperature (47.2°C), and the minimum room air temperature will be 16.8°C higher than minimum outdoor temperature (21.6°C). In the case of the roof made of hollow concrete slab, the temperature difference will be 7.7°C and 17.1°C respectively, which is practically the same as for the first case. It can also be seen that maximum inside surface temperature of the roof (ceiling surface) made of the 100 mm solid slab will be 1.6°C higher than maximum ceiling surface temperature of the roof made of hollow slab.

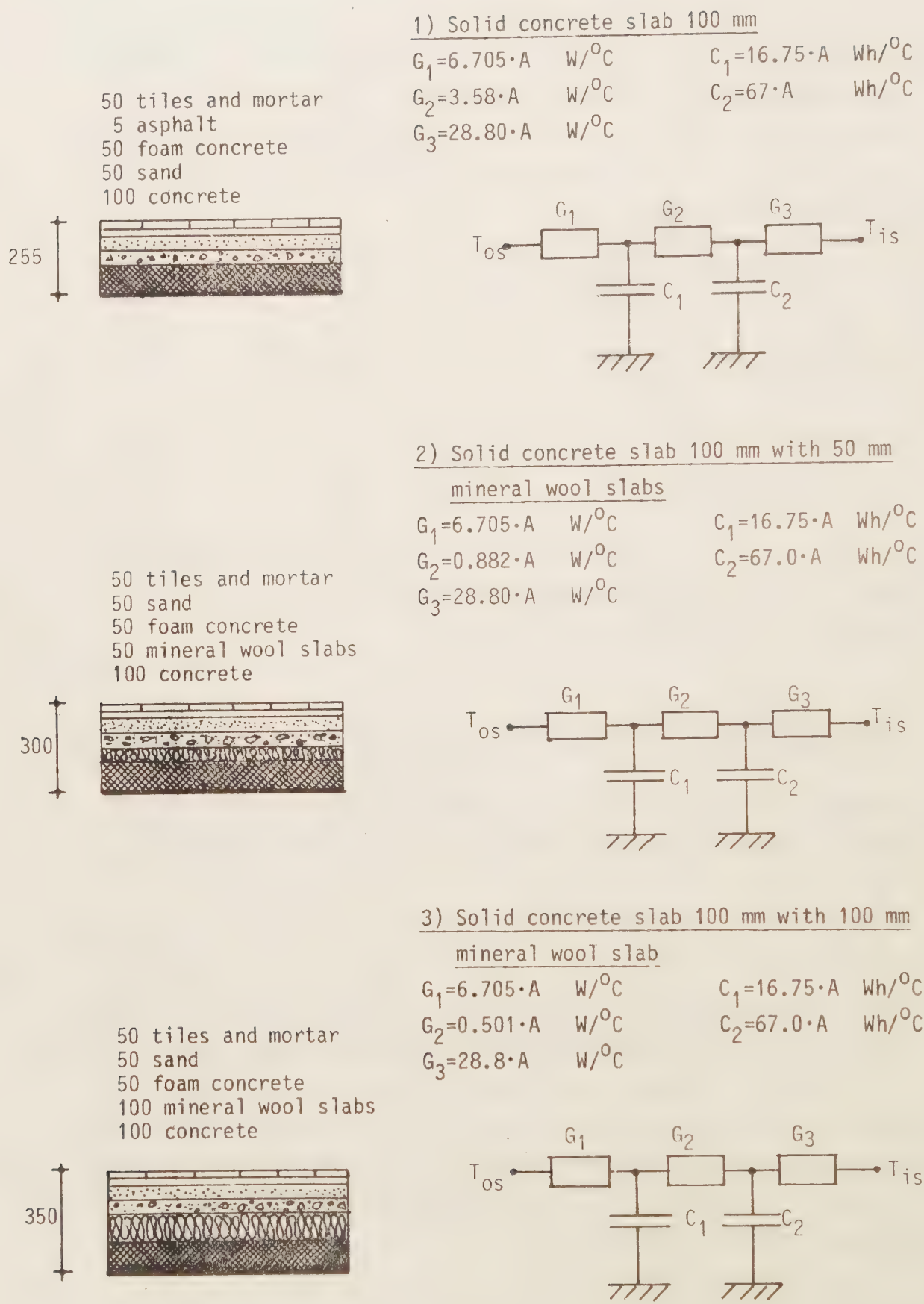
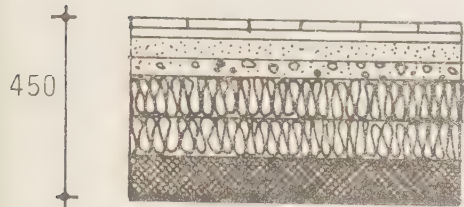


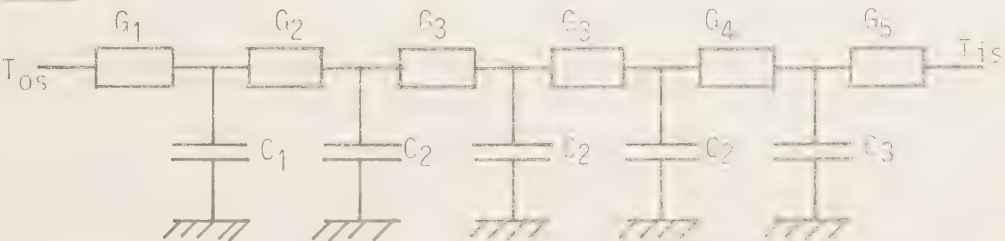
Figure 5.3.1 Design and simulation alternative for roofs.

50 tiles and mortar
50 sand
50 foam concrete
200 mineral wool
100 concrete



4) Concrete slab 100 mm with 200 mm
mineral wool slabs

$G_1=6.705 \cdot A$	$W/^{\circ}C$	$C_1=16.75 \cdot A$	$Wh/^{\circ}C$
$G_2=1.232 \cdot A$	$W/^{\circ}C$	$C_2=6.6 \cdot A$	$Wh/^{\circ}C$
$G_3=0.87 \cdot A$	$W/^{\circ}C$	$C_3=67.0 \cdot A$	$Wh/^{\circ}C$
$G_4=1.64 \cdot A$	$W/^{\circ}C$		
$G_5=28.80 \cdot A$	$W/^{\circ}C$		

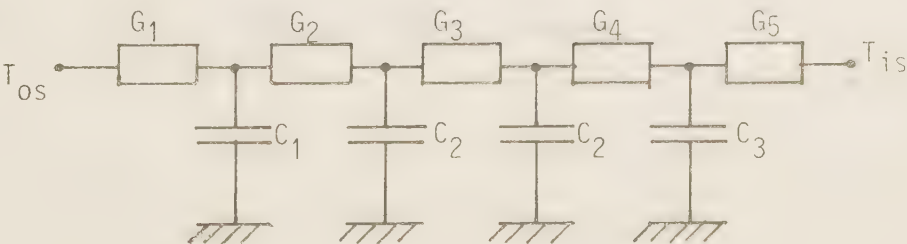


5) Concrete slab 100 mm with 50 mm mineral
wool on ceiling

50 tiles and mortar
50 sand
50 foam concrete
100 concrete
50 mineral wool
25 wood panel

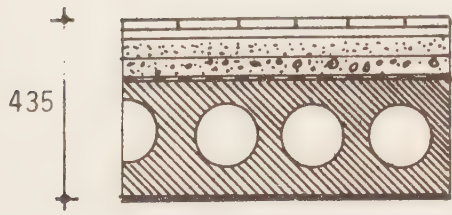


$G_1=6.705 \cdot A$	$W/^{\circ}C$	$C_1=16.75 \cdot A$	$Wh/^{\circ}C$
$G_2=3.937 \cdot A$	$W/^{\circ}C$	$C_2=33.50 \cdot A$	$Wh/^{\circ}C$
$G_3=28.80 \cdot A$	$W/^{\circ}C$	$C_3=4.95 \cdot A$	$Wh/^{\circ}C$
$G_4=2.23 \cdot A$	$W/^{\circ}C$		
$G_5=1.64 \cdot A$	$W/^{\circ}C$		



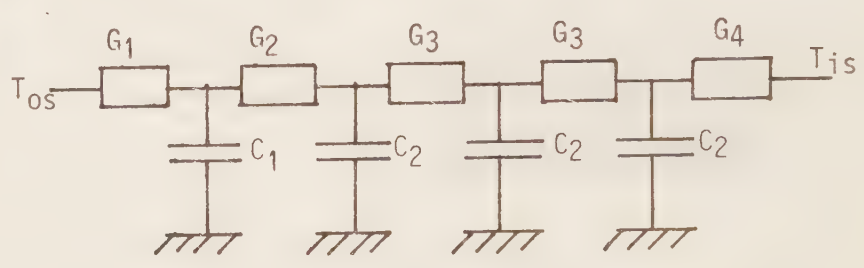
176.

50 tiles and mortar
50 sand
50 foam concrete
5 p.p.c.
280 hollow concrete

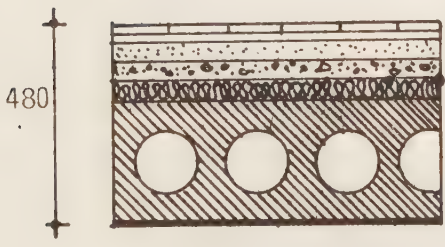


6) Hollow concrete slab 280 mm

$G_1 = 6.705 \cdot A$	$W/^{\circ}C$	$C_1 = 16.75 \cdot A$	$Wh/^{\circ}C$
$G_2 = 2.942 \cdot A$	$W/^{\circ}C$	$C_2 = 28.18 \cdot A$	$Wh/^{\circ}C$
$G_3 = 5.185 \cdot A$	$W/^{\circ}C$		
$G_4 = 10.37 \cdot A$	$W/^{\circ}C$		

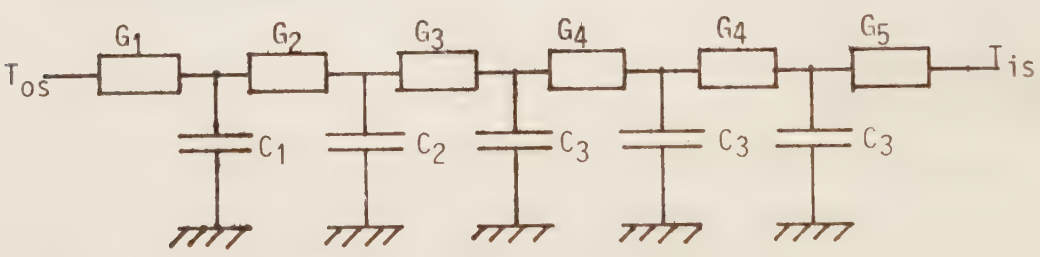


50 tiles and mortar
50 sand
50 foam concrete
50 mineral wool
280 hollow concrete

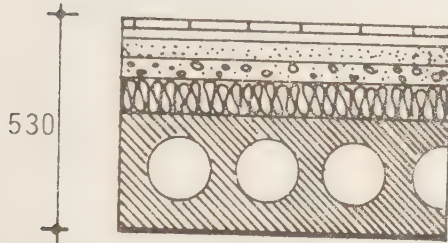


7) Hollow concrete slab 280 mm with 50 mm mineral wool

$G_1 = 3.26 \cdot A$	$W/^{\circ}C$	$C_1 = 8.70 \cdot A$	$Wh/^{\circ}C$
$G_2 = 1.958 \cdot A$	$W/^{\circ}C$	$C_2 = 4.92 \cdot A$	$Wh/^{\circ}C$
$G_3 = 1.895 \cdot A$	$W/^{\circ}C$	$C_3 = 28.18 \cdot A$	$Wh/^{\circ}C$
$G_4 = 5.184 \cdot A$	$W/^{\circ}C$		
$G_5 = 10.368 \cdot A$	$W/^{\circ}C$		



50 tiles and mortar
50 sand
50 foam concrete
100 mineral wool
280 hollow concrete



8) Hollow concrete slab 280 mm with 100 mm mineral wool

$$G_1 = 3.266 \cdot A \text{ W/}^\circ\text{C}$$

$$C_1 = 8.70 \cdot A \text{ Wh/}^\circ\text{C}$$

$$G_2 = 1.958 \cdot A \text{ W/}^\circ\text{C}$$

$$C_2 = 4.95 \cdot A \text{ Wh/}^\circ\text{C}$$

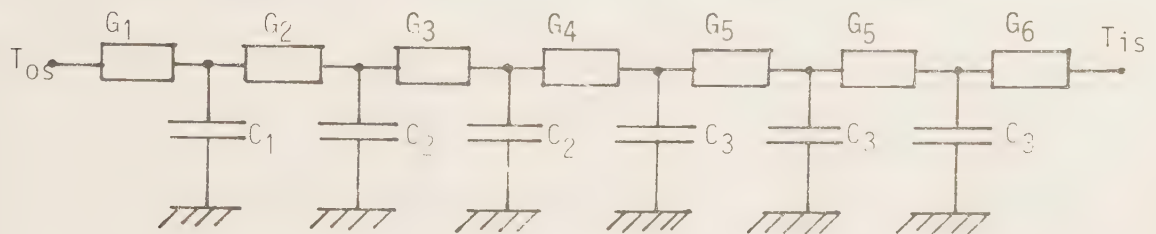
$$G_3 = 1.16 \cdot A \text{ W/}^\circ\text{C}$$

$$C_3 = 28.18 \cdot A \text{ Wh/}^\circ\text{C}$$

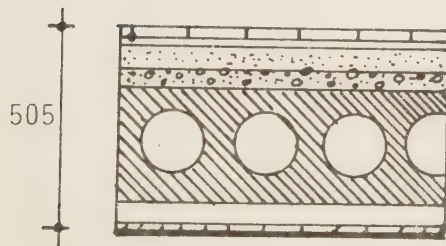
$$G_4 = 1.895 \cdot A \text{ W/}^\circ\text{C}$$

$$G_5 = 5.184 \cdot A \text{ W/}^\circ\text{C}$$

$$G_6 = 10.368 \cdot A \text{ W/}^\circ\text{C}$$



50 mortar and tiles
50 sand
50 foam concrete
280 hollow concrete
50 air space
25 wood panel



9) Hollow concrete slab 280 mm with suspended ceiling

$$G_1 = 6.705 \cdot A \text{ W/}^\circ\text{C}$$

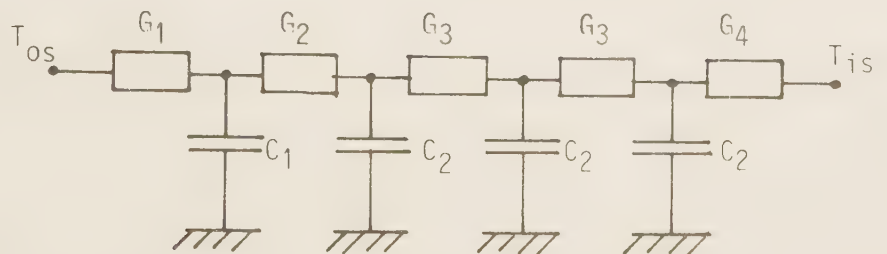
$$C_1 = 16.75 \cdot A \text{ Wh/}^\circ\text{C}$$

$$G_2 = 3.00 \cdot A \text{ W/}^\circ\text{C}$$

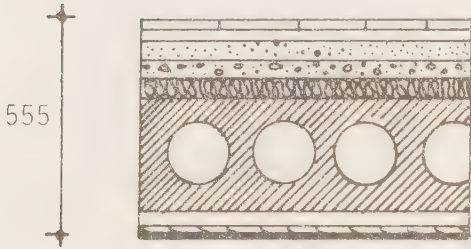
$$C_2 = 28.18 \cdot A \text{ Wh/}^\circ\text{C}$$

$$G_3 = 5.184 \cdot A \text{ W/}^\circ\text{C}$$

$$G_4 = 2.24 \cdot A \text{ W/}^\circ\text{C}$$

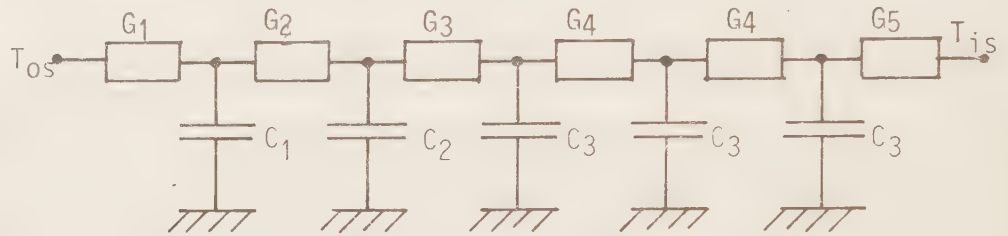


50 tiles and mortar
 50 sand
 50 foam concrete
 50 mineral wool
 280 hollow concrete
 50 air space
 25 wood panels



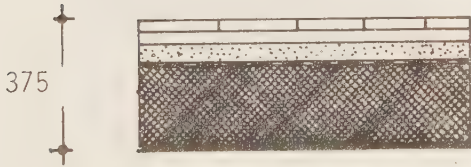
10) Hollow concrete slab 280 mm with 50 mm
 mineral wool and suspended ceiling

$G_1 = 6.705 \cdot A$	$W/^{\circ}C$	$C_1 = 16.75 \cdot A$	$Wh/^{\circ}C$
$G_2 = 1.49 \cdot A$	$W/^{\circ}C$	$C_2 = 4.95 \cdot A$	$Wh/^{\circ}C$
$G_3 = 1.89 \cdot A$	$W/^{\circ}C$	$C_3 = 28.18 \cdot A$	$Wh/^{\circ}C$
$G_4 = 5.18 \cdot A$	$W/^{\circ}C$		
$G_5 = 2.25 \cdot A$	$W/^{\circ}C$		

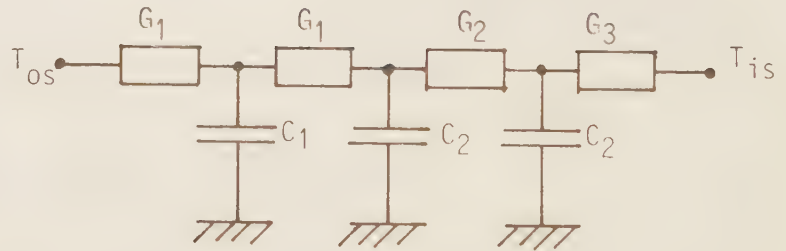


11) Concrete slab 200 mm

45 tiles and mortar
 50 sand
 2 asphalt
 200 concrete



$G_1 = 7.0 \cdot A$	$W/^{\circ}C$	$C_1 = 16.75 \cdot A$	$Wh/^{\circ}C$
$G_2 = 14.4 \cdot A$	$W/^{\circ}C$	$C_2 = 67.0 \cdot A$	$Wh/^{\circ}C$
$G_3 = 28.8 \cdot A$	$W/^{\circ}C$		



When the thermal capacity of the roof is increased by increasing the thickness of the solid concrete slab from 100 mm to 200 mm (see Table 5.3.1), it can be seen that maximum room air temperature will be 0.2°C lower than maximum room air temperature when the roof is 100 mm thick. For maximum ceiling surface temperature, the difference will be 0.6°C . This result means that increasing thermal capacity of the roof has an insignificant effect on indoor temperature.

When the room is ventilated with 5 air changes per hour (see Table 5.3.2) and the roof is made of solid concrete slab, 100 mm thick, the maximum room air temperature will be 37.9°C and the minimum room air temperature will be 31.7°C . If the room has a roof of solid concrete slab, 200 mm thick (increased thermal capacity of the roof), the maximum room air temperature will be 37.6°C and the minimum room air temperature will be 31.0°C . A comparison between ceiling surface temperature in both cases shows that the maximum ceiling temperature of the 200 mm roof will be 0.5°C lower than the ceiling surface temperature of the 100 mm roof.

This result means that increasing the thermal capacity of the roof is of limited value. When the roof is made of a hollow concrete slab, minimum and maximum temperature will be lower than in the case of solid concrete slab 200 mm thick. This emphasizes that a roof with high thermal resistance has advantages in reducing indoor temperature compared with a roof with high thermal capacity.



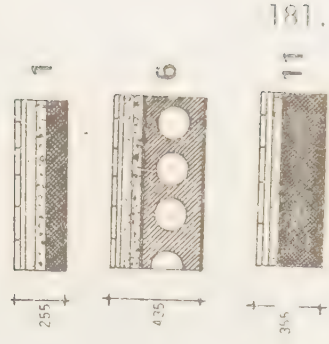
Table 5.3.1 Influence of thermal capacity and resistance of the roof on indoor temperature.

Type of roof	Inside surface temperature (°C)									
	Room air temperature		South		North		West		East	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1) 100 mm concrete slab	40.0	38.4	39.6	37.9	40.0	38.2	40.5	38.6	40.4	38.5
6) 280 mm hollow concrete slab	39.5	38.7	39.3	37.9	39.7	38.3	40.2	38.6	40.0	38.6
11) 200 mm concrete	39.8	38.7	39.6	38.1	40.0	38.3	40.5	38.7	40.4	38.6

Outdoor air temperature; max = 47.2 °C, min = 21.6 °C. Roof types according to Figure 5.3.1.

Table 5.3.2 Influence of thermal capacity of the roof and room ventilation condition on indoor temperature.

Time of day	Ventilation 2.5 air changes/h						Ventilation 5 air changes/h					
	Room air			Ceiling surface			Room air			Ceiling surface		
	Roof type			Roof type			Roof type			Roof type		
h	1	6	11	1	6	11	1	6	11	1	6	11
01.00	34.6	34.2	34.6	38.5	37.9	39.0	32.0	31.6	32.0	37.7	36.8	38.2
02.00	34.3	34.0	34.5	38.1	37.8	38.7	31.7	31.4	31.0	37.2	36.7	37.9
03.00	34.2	34.0	34.4	37.6	37.7	38.5	31.7	31.5	31.9	36.7	36.5	37.6
04.00	34.4	34.3	34.6	37.2	37.6	38.2	32.0	31.8	32.2	36.3	36.4	37.3
05.00	34.8	34.7	34.9	36.8	37.5	37.9	32.6	32.5	32.8	35.9	36.4	37.1
06.00	35.2	35.2	35.4	36.5	37.4	37.6	33.5	33.4	33.7	35.6	36.4	36.8
07.00	35.9	35.9	36.1	36.2	37.4	37.4	34.6	34.7	34.9	35.4	36.4	36.6
08.00	36.8	37.2	37.3	36.1	37.4	37.3	35.9	36.2	36.5	35.3	36.5	36.5
09.00	36.7	37.2	37.3	36.2	37.3	37.1	35.9	36.3	36.5	35.4	36.4	36.4
10.00	36.8	37.2	37.3	36.4	37.2	37.1	36.0	36.3	36.5	35.6	36.4	36.3
11.00	37.0	37.1	37.3	36.7	37.1	37.1	36.3	36.3	36.6	35.9	36.3	36.4
12.00	37.3	37.1	37.3	37.2	37.1	37.2	36.5	36.4	36.7	39.4	36.3	36.5
13.00	37.4	37.2	37.5	37.7	37.1	37.4	36.6	36.4	36.8	37.0	36.3	36.8
14.00	37.6	37.2	37.6	38.3	37.1	37.7	36.9	36.5	37.0	37.6	36.3	37.1
15.00	37.8	37.3	37.7	38.9	37.2	38.1	37.1	36.6	37.0	38.2	36.4	37.4
16.00	38.0	37.4	37.8	39.4	37.3	38.5	37.3	36.6	37.2	38.7	36.6	37.8
17.00	38.3	37.5	38.0	39.8	37.4	38.8	37.6	36.8	37.4	39.2	36.7	38.2
18.00	38.4	37.6	38.2	40.1	37.6	39.2	37.9	36.9	37.6	39.5	36.9	38.6
19.00	37.6	37.1	37.5	40.2	37.7	39.4	36.9	36.4	36.9	39.6	37.1	38.8
20.00	37.0	36.5	36.9	40.2	37.8	39.6	35.9	35.4	35.8	39.5	37.1	38.0
21.00	36.4	35.7	36.3	40.0	37.9	39.6	34.9	34.3	34.8	39.3	37.2	39.0
22.00	35.7	35.3	35.7	39.7	38.0	39.6	33.9	33.4	33.9	39.0	37.1	38.9
23.00	35.4	34.7	35.3	39.4	38.0	39.4	33.1	32.7	33.2	38.6	37.1	38.7
24.00	34.9	34.5	34.9	39.0	37.9	39.3	32.5	32.1	32.5	38.2	37.0	38.5



Outdoor air temperatures: max = 47.2 oC, min = 21.6 oC. Roof type according to Figure 5.3.1

5.3.2 Influence of thermal insulation of the roof on indoor temperature

A comparison was made between four types of roof construction with different insulation

- 1) 100 mm solid concrete slab without insulation
- type 1 in Figure 5.3.1
- 2) with 50 mm insulation (mineral wool) above the slab
- type 2
- 3) with insulation 100 mm thick above the slab
- type 3
- 4) with insulation 200 mm thick above the slab
- type 4

It can be seen from Table 5.3.3 that the maximum room air temperature for the uninsulated slab reaches 39.9°C . With 50 mm insulation the maximum temperature is reduced to 39.5°C , with 100 mm to 39.1°C and with 200 mm insulation to 38.9°C .

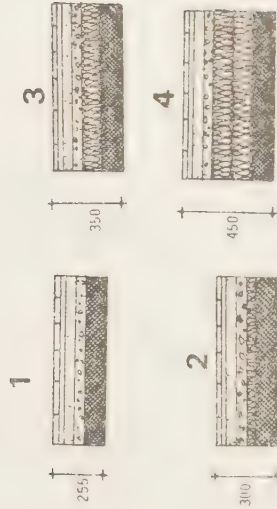
It can also be seen from Table 5.3.3 that maximum ceiling surface temperature of the roof without insulation will be 41.4°C , with 50 mm insulation 39.9°C , with 100 mm insulation 39.2°C and with 200 mm insulation 38.9°C . This result means that insulation of more than 100 mm has only a slight effect on the indoor temperatures.

Table 5.3.4 shows a comparison of room air temperature in night-ventilated rooms without roof insulation and with insulation of 50, 100 and 200 mm thickness. When the room is ventilated with 5 air changes per hour the roof without insulation gives a maximum room air temperature = 37.9°C . When the roof is insulated with 50 mm thickness, the maximum room air temperature will decrease to 36.9°C , with 200 mm to 36.3°C . This result shows that even in a night-ventilated room, the thickness of the insulation on a solid slab above 50 mm has only a slight effect on indoor temperature.

When the roof is made of a hollow concrete slab with different thicknesses of insulation and the room ventilated at night with 2.5 air changes per hour (Table 5.3.5), the difference between maximum ceiling surface temperature of the roof without insulation and with 50 mm in-

Table 5.3.3 Influence of insulation thickness of the roof on room air and ceiling surface temperature.

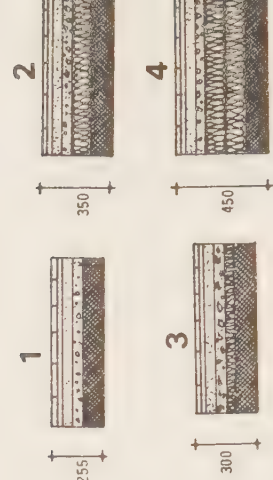
Time of day	Room air temperature (°C)				Ceiling surface temp.(°C)			
	Roof type				Roof type			
	1	2	3	4	1	2	3	4
01.00	39.7	39.5	39.1	38.9	40.0	39.7	39.1	38.8
02.00	39.5	39.5	39.0	38.9	40.6	39.5	39.1	38.8
03.00	39.3	39.4	39.0	38.9	39.2	39.4	39.0	38.8
04.00	39.1	39.3	38.9	38.8	38.8	39.3	38.9	38.9
05.00	39.0	39.2	38.8	38.8	38.4	39.1	38.8	38.9
06.00	38.7	39.0	38.7	38.7	38.1	39.0	38.7	38.8
07.00	38.5	38.9	38.6	38.7	37.8	38.8	38.6	38.8
08.00	38.5	38.8	38.5	38.6	37.7	38.7	38.5	38.8
09.00	38.4	38.8	38.5	38.5	37.7	38.6	38.5	38.8
10.00	38.4	38.7	38.5	38.5	37.8	38.6	38.5	38.8
11.00	38.4	38.7	38.5	38.5	38.1	38.7	38.5	38.7
12.00	38.6	38.7	38.5	38.5	38.5	38.8	38.5	38.7
13.00	38.7	38.7	38.5	38.4	39.0	38.9	38.6	38.6
14.00	38.9	38.8	38.6	38.5	39.6	39.0	38.7	38.6
15.00	39.1	38.9	38.7	38.5	40.1	39.2	38.8	38.6
16.00	39.3	39.0	38.7	38.5	40.6	39.4	38.9	38.6
17.00	39.4	39.0	38.8	38.6	41.0	39.6	39.0	38.6
18.00	39.6	39.2	38.9	38.6	41.3	39.7	39.1	38.6
19.00	39.7	39.2	38.8	38.7	41.4	39.8	39.2	38.6
20.00	39.8	39.3	38.3	38.7	41.4	39.9	39.2	38.6
21.00	39.9	39.4	39.1	38.8	41.2	39.9	39.2	38.7
22.00	39.9	39.5	39.1	38.9	41.0	39.9	39.2	38.7
23.00	39.9	39.5	39.1	39.0	40.7	39.8	39.2	38.7
24.00	39.8	39.5	39.2	39.0	40.4	39.7	39.2	38.8



Outdoor air temperature: max = 47.2 °C, min = 21.6 °C.
Roof types according to Figure 5.3.1.

Table 5.3.4 Influence of ventilation rate at night of room and type of roof on indoor air temperature.

Time of day	Room air temperature (°C)											
	2.5 air changes/h				5 air changes/h				10 air changes/h			
	Roof type				Roof type				Roof type			
h	1	2	3	4	1	2	3	4	1	2	3	4
01.00	34.6	34.1	33.9	33.7	32.0	31.5	31.4	31.2	29.1	28.8	28.7	28.5
02.00	34.3	33.9	33.7	33.6	31.7	31.3	31.3	31.0	28.8	28.4	28.4	28.3
03.00	34.2	33.9	33.7	33.6	31.7	31.4	31.3	31.1	28.9	28.0	28.6	28.4
04.00	34.4	34.1	34.0	33.9	32.0	31.7	31.7	31.5	29.5	29.2	29.2	29.0
05.00	34.8	34.5	34.4	34.4	32.6	32.4	32.4	32.2	30.4	30.2	30.2	30.1
06.00	35.2	35.0	34.9	34.8	33.5	33.3	33.3	33.1	31.8	31.7	31.7	31.5
07.00	35.9	35.7	35.6	35.6	34.6	34.5	34.5	34.4	33.6	33.4	33.5	33.4
08.00	36.8	36.9	36.8	36.8	35.9	35.9	35.9	35.7	35.1	34.9	34.9	34.7
09.00	36.7	36.9	36.8	36.8	35.9	35.9	36.0	35.8	35.1	34.9	35.0	34.8
10.00	36.8	36.9	36.8	36.8	36.0	35.9	36.0	35.9	35.3	35.0	35.0	34.9
11.00	37.0	36.9	36.8	36.8	36.3	36.0	36.1	35.9	35.4	35.1	35.1	34.9
12.00	37.3	37.0	36.8	36.8	36.5	36.1	36.2	36.0	35.6	35.3	35.2	35.0
13.00	37.4	37.1	36.9	36.9	36.6	36.2	36.3	36.1	35.9	35.4	35.3	35.1
14.00	37.6	37.2	37.0	36.9	36.9	36.3	36.4	36.1	36.1	35.5	35.4	35.2
15.00	37.8	37.3	37.1	37.0	37.1	36.4	36.4	36.2	36.4	35.7	35.5	35.2
16.00	38.0	37.4	37.2	37.0	37.3	36.6	36.5	36.2	36.7	35.8	35.7	35.3
17.00	38.3	37.5	37.2	37.1	37.6	36.7	36.6	36.2	36.9	36.0	35.9	35.4
18.00	38.4	37.6	37.4	37.1	37.9	36.9	36.8	36.3	37.1	36.1	35.9	35.5
19.00	37.6	37.1	36.9	36.8	36.9	36.4	36.4	36.2	36.4	36.0	36.0	35.8
20.00	37.0	36.5	36.3	36.1	35.9	35.3	35.2	35.0	34.8	34.3	34.2	34.0
21.00	36.4	35.8	35.5	35.4	34.9	34.3	34.2	34.0	33.3	32.8	32.7	32.5
22.00	35.7	35.3	35.1	34.9	33.9	33.4	33.3	33.1	31.9	31.5	31.4	31.2
23.00	35.4	34.7	34.6	34.4	33.1	32.6	32.6	32.3	30.7	30.3	30.2	30.1
24.00	34.9	34.4	34.2	34.1	32.5	32.0	31.9	31.7	29.8	29.4	29.3	29.1



Outdoor air temperature: max = 47.2 °C, min = 21.6 °C. Roof types according to Figure 5.3.1

Table 5.3.5 Influence of night ventilation on room air and inside surface temperature.

Roof type	No. of airch/h	Room air tempera- ture	Inside surface temperature (°C)																	
			South		North		West		East		Roof		Floor		Window		Door			
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
6		2.5	37.6	34.0	37.3	36.5	37.6	36.8	37.9	37.1	38.1	37.1	38.0	37.1	37.2	36.4	41.5	30.6	40.0	34.0
		5	36.9	31.4	36.5	35.5	36.8	35.8	37.1	36.3	37.4	36.1	37.2	36.3	36.4	34.9	41.0	29.5	39.4	32.8
		10	36.4	28.6	35.9	34.3	36.3	34.6	36.5	34.9	36.8	34.8	36.6	35.4	35.8	33.5	40.6	28.5	38.9	31.5
7		2.5	37.4	33.8	37.0	36.4	37.3	36.6	37.7	36.9	37.8	36.9	37.3	36.9	36.9	36.1	41.4	30.4	39.9	33.8
		5	36.7	31.2	36.3	35.3	36.6	35.6	36.9	36.0	37.2	35.8	36.6	35.9	36.2	34.6	40.9	29.3	39.3	32.6
		10	36.0	28.4	35.6	33.9	35.9	34.2	36.2	34.6	36.5	34.4	35.8	34.6	35.3	32.9	40.4	28.2	38.6	31.1
8		2.5	37.3	33.7	36.9	36.3	37.3	36.6	37.6	36.9	37.8	36.8	37.1	36.7	36.8	35.9	41.4	30.3	39.8	33.7
		5	36.5	31.1	36.2	35.1	36.6	35.4	36.7	35.9	37.1	35.7	36.3	35.5	36.0	34.4	40.9	29.2	39.2	32.9
		10	35.9	28.3	35.5	33.8	35.8	34.1	36.1	34.5	36.4	34.3	35.6	34.2	35.2	32.9	40.3	28.1	38.5	31.0

Outdoor air temperature: max = 47.2 °C, min = 21.6 °C. Roof types according to Figure 5.3.1.

sulation will be 0.7°C . The difference between maximum ceiling surface temperatures when the roof is insulated with 50 mm and with 100 mm thickness will be 0.2°C . The minimum ceiling surface temperature difference will be 0.1°C and about 0.2°C respectively.

When the room is ventilated at night with 5 air changes per hour, the difference between maximum ceiling temperature of the roof without insulation and the roof with 50 mm thick insulation is 0.6°C , and the difference between ceiling surface temperature of the roof with 50 mm thick insulation and with 100 mm thick insulation is 0.3°C .

This means that an insulation thickness of more than 50 mm, even when the roof is made of hollow concrete slab and the room is night-ventilated, has little effect on indoor temperatures.

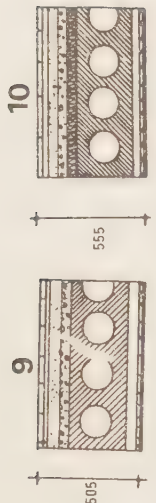
Table 5.3.6 shows that when insulation is laid on the ceiling surface, or there is a suspended ceiling and the roof is made of a 100 mm solid concrete slab and 50 mm insulation (type 5 in Figure 5.3.1), the maximum room air temperature will be 39.4°C . When the roof is made of a hollow concrete slab with a suspended ceiling (type 9), the maximum room air temperature will be at the same level as for type 5. But when the roof is made of a hollow concrete slab with 50 mm insulation below and a suspended ceiling (type 10), the maximum room air temperature will be 0.2°C lower than achieved for type 9 (without insulation) and the maximum ceiling temperature will decrease with 0.6°C .

When the room is night-ventilated with 2.5 air changes per hour (Table 5.3.7), and the roof is made of a solid concrete slab with 50 mm insulation (type 5), the maximum room air temperature is 37.6°C and the minimum room air temperature is 33.9°C . In the case of the roof made of a hollow concrete slab with a suspended ceiling, the temperatures are the same. When the roof is made of a hollow concrete slab with a suspended ceiling and 50 mm insulation, the maximum and minimum room air temperatures will be 37.4°C and 33.7°C , respectively. This result emphasizes that insulation below a 280 mm hollow concrete slab has very little effect on the indoor air temperature.

Table 5.3.7 Influence of night ventilation on room air and ceiling surface temperature.

Time of day	2.5 air changes/h										5 air changes/h									
	Room air temp.					Ceiling surface temp					Room air temp.					Ceiling surface temp.				
	Roof type					Roof type					Roof type					Roof type				
h	5	9	10	5	10	9	5	10	5	10	9	5	10	9	5	10	9	5	10	9
01.00	34.0	34.0	33.8	37.2	37.3	36.8	31.3	31.4	31.2	31.2	31.4	31.2	31.0	31.1	35.9	36.0	35.3	35.9	35.4	35.3
02.00	33.8	33.8	33.6	37.0	37.2	36.7	31.2	31.2	31.2	31.2	31.2	31.2	31.0	31.1	35.7	35.9	35.4	35.7	35.4	35.3
03.00	33.8	33.8	33.7	36.9	37.1	36.7	31.2	31.3	31.1	31.3	31.3	31.1	31.1	31.1	35.5	35.8	35.3	35.8	35.3	35.3
04.00	34.0	34.1	33.9	36.8	37.1	36.6	31.6	31.6	31.5	31.6	31.6	31.5	31.5	31.5	35.4	35.8	35.3	35.4	35.3	35.3
05.00	34.5	34.6	34.4	36.7	37.1	36.7	32.3	32.2	32.2	32.2	32.2	32.2	32.2	32.2	35.5	35.9	35.4	35.5	35.4	35.4
06.00	35.0	35.1	34.9	36.8	37.1	36.8	33.2	33.3	33.2	33.2	33.3	33.2	33.2	33.2	35.6	36.0	35.6	35.6	35.6	35.6
07.00	35.7	35.8	35.6	36.9	37.2	36.9	34.5	34.6	34.4	34.4	34.6	34.4	34.4	34.4	35.9	36.2	35.9	36.2	35.9	35.9
08.00	36.9	37.1	36.9	37.0	37.4	37.1	36.0	36.2	35.9	35.9	36.2	35.9	35.9	35.9	36.1	36.5	36.7	36.5	36.7	36.7
09.00	36.9	37.1	36.9	37.0	37.3	37.1	36.0	36.2	36.0	36.2	36.2	36.0	36.0	36.0	36.1	36.5	36.2	36.1	36.2	36.2
10.00	36.9	37.1	36.9	36.9	37.3	37.1	36.1	36.2	36.1	36.2	36.2	36.1	36.0	36.1	36.1	36.4	36.2	36.4	36.2	36.2
11.00	37.0	37.1	37.0	36.9	37.2	37.1	36.1	36.3	36.1	36.3	36.3	36.1	36.1	36.1	36.2	36.4	36.2	36.4	36.2	36.2
12.00	37.0	37.1	37.0	37.0	37.2	37.1	36.2	36.3	36.2	36.3	36.3	36.2	36.2	36.2	36.2	36.4	36.2	36.4	36.2	36.2
13.00	37.1	37.2	37.1	37.0	37.2	37.1	36.3	36.4	36.3	36.4	36.4	36.2	36.2	36.2	36.3	36.4	36.3	36.4	36.3	36.3
14.00	37.2	37.2	37.1	37.2	37.2	37.1	36.4	36.5	36.3	36.5	36.5	36.4	36.3	36.3	36.4	36.5	36.3	36.4	36.3	36.3
15.00	37.3	37.3	37.2	37.3	37.3	37.1	36.5	36.5	36.5	36.5	36.5	36.5	36.4	36.4	36.6	36.6	36.4	36.6	36.4	36.4
16.00	37.4	37.4	37.3	37.5	37.4	37.2	36.6	36.6	36.5	36.6	36.6	36.5	36.5	36.5	36.8	36.7	36.4	36.7	36.4	36.4
17.00	37.4	37.5	37.3	37.7	37.5	37.3	36.8	36.7	36.6	36.7	36.7	36.8	36.6	36.6	37.0	36.8	36.5	36.8	36.5	36.5
18.00	37.5	37.5	37.3	37.8	37.6	37.3	36.9	36.9	36.7	36.9	36.9	36.9	36.7	36.7	37.2	36.9	36.6	36.9	36.6	36.6
19.00	37.0	37.0	36.9	37.9	37.6	37.3	36.4	36.4	36.3	36.4	36.4	36.4	36.3	36.3	37.3	37.0	36.6	37.0	36.6	36.6
20.00	36.4	36.4	36.2	37.9	37.6	37.3	35.3	35.3	35.1	35.3	35.3	35.3	35.1	35.1	37.1	36.9	36.5	36.9	36.5	36.5
21.00	35.7	35.6	35.5	37.8	37.6	37.2	34.2	34.2	34.1	34.2	34.2	34.2	34.1	34.1	36.0	36.7	36.3	36.7	36.3	36.3
22.00	35.2	35.2	35.0	37.7	37.5	37.1	33.3	33.2	33.2	33.2	33.2	33.3	33.2	33.2	36.7	36.6	36.1	36.6	36.1	36.1
23.00	34.6	34.6	34.5	37.5	37.5	37.0	32.5	32.5	32.4	32.5	32.5	32.5	32.4	32.4	36.4	36.4	35.9	36.4	35.9	35.9
24.00	34.3	34.3	34.2	37.4	37.4	36.9	31.9	31.9	31.7	31.9	31.9	31.9	31.7	31.7	36.2	36.2	35.7	36.2	35.7	35.7

Outdoor air temperature: max = 47.2 °C, min = 21.6 °C. Roof types according to Figure 5.3.1.



5.3.3 Influence of colour of the roof on indoor temperature

The roof surface receives the largest amount of solar radiation of all building surfaces, about 37% of the total. Table 5.3.8 shows the maximum and minimum indoor temperatures of a room which has a roof made of 100 mm solid concrete slab with 50 mm insulation on the external roof surface (type 2 in Figure 5.3.1). As these temperatures vary with the absorption, it is assumed that the absorptivity is 0.01 or 0.1 for shaded roof and 0.3 for white and 0.8 for dark colours. It can be seen that, when the roof has a dark colour, maximum and minimum room air temperature will be 1.0°C higher than that of the house with white roof colour. It can also be noted that maximum ceiling surface temperature when the roof has dark colour is 4°C higher than that of the shaded roof ($a=0.1$), the minimum ceiling surface temperature is 2.5°C higher.

According to Table 5.3.9, which shows influence of roof absorptivity for two types of roof construction on indoor temperature, treatment of roof surface by light colour or protection against solar radiation by any shading device is more effective in reduction of indoor temperature than normal measures to increase the thermal capacity or resistance of the roof.

Table 5.3.8 Influence of roof colour on room air and ceiling surface temperatures

Time of day	Room air temperature (°C)				Ceiling surface temperature (°C)			
	Roof type 2		Roof type 7		Roof type 2		Roof type 7	
	a=0.1	a=0.3	a=0.8	a=0.1	a=0.3	a=0.8	a=0.1	a=0.3
h	a=0.8	a=0.3	a=0.1	a=0.8	a=0.3	a=0.1	a=0.8	a=0.3
01.00	38.6	39.5	40.6	38.6	39.1	40.2	38.4	39.7
02.00	38.5	39.5	40.5	38.6	39.1	40.2	38.4	39.5
03.00	38.5	39.4	40.4	38.6	39.0	40.1	38.3	39.4
04.00	38.4	39.3	40.3	38.5	39.0	40.1	38.2	39.3
05.00	38.3	39.2	40.2	38.5	38.9	40.0	38.0	39.1
06.00	38.3	39.0	40.1	38.4	38.9	40.0	37.9	39.0
07.00	38.2	38.9	39.9	38.3	38.8	39.9	37.8	38.8
08.00	38.1	38.8	39.8	38.2	38.7	39.8	37.7	38.7
09.00	38.0	38.8	39.7	38.2	38.6	39.7	37.7	38.6
10.00	37.9	38.7	39.7	38.2	38.6	39.7	37.7	38.6
11.00	37.9	38.7	39.6	38.2	38.5	39.7	37.7	38.7
12.00	37.9	38.7	39.7	38.1	38.5	39.6	37.7	38.8
13.00	37.9	38.7	39.8	38.1	38.5	39.6	37.8	38.9
14.00	38.0	38.8	39.9	38.1	38.5	39.6	37.9	39.0
15.00	38.1	38.9	40.0	38.2	38.5	39.6	38.0	39.2
16.00	38.2	39.0	40.2	38.2	38.6	39.6	38.2	39.4
17.00	38.3	39.0	40.3	38.2	38.6	39.7	38.3	39.6
18.00	38.3	39.2	40.5	38.3	38.6	39.7	38.4	39.7
19.00	38.4	39.2	40.5	38.3	38.7	39.8	38.5	39.8
20.00	38.5	39.3	40.6	38.4	38.8	39.9	38.5	39.9
21.00	38.6	39.4	40.7	38.5	38.9	40.0	38.6	39.9
22.00	38.6	39.5	40.7	38.6	39.0	40.1	38.6	39.9
23.00	38.7	39.5	40.8	38.6	39.1	40.2	38.6	39.8
24.00	38.7	39.5	40.7	38.6	39.1	40.2	38.5	39.7

Outdoor air temperature: max = 47.2 °C, min = 21.6 °C. Roof types according to Figure 5.3.1. Absorptivity of roof surface = a.

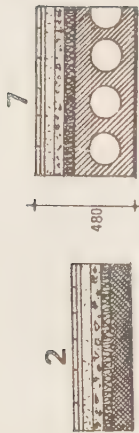


Table 5.3.9 Influence of roof colour on room air and inside surface temperature.

Roof type	Absorp- tivity	Room air temp	Inside surface temperature (°C)																
			South		North		West		East		Roof		Floor		Window		Door		
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
 300	0.01	38.6	37.8	38.4	37.2	38.8	37.5	39.3	37.8	39.2	37.8	38.2	37.4	38.0	37.6	41.9	32.1	40.5	35.6
	0.1	38.7	37.9	38.7	37.4	39.0	37.7	39.5	37.9	39.4	37.9	38.6	37.7	38.3	37.9	42.1	32.3	40.8	35.8
	0.3	39.6	38.7	39.4	38.1	39.8	38.4	40.3	38.7	40.1	38.6	39.9	38.7	39.3	38.7	42.6	32.9	41.5	36.5
	0.8	40.8	39.7	40.5	39.0	40.9	39.3	41.3	39.6	41.2	39.6	42.4	40.2	40.5	39.7	43.3	33.7	42.5	37.4

Outdoor air temperature: max = 47.2 °C, min = 21.6 °C. Roof type according to Figure 5.3.1.

5.4 INFLUENCE OF THE WINDOW ON INDOOR TEMPERATURES

First I would like to review some opinions in the literature concerning windows in a hot, arid climate. Several authors such as Saini (1973) and Lippsmeier (1969), recommend small windows as preferable in hot climates. Small windows are assumed to reduce the quantity of solar radiation which penetrates into the building.

In old traditional buildings, obviously no window is found towards the street, but what is the reason? Is it to prevent solar radiation from penetrating into the interior, or is it social aspects? Count (1890) said that "no window overlooks the street or they are placed at such a height that a man on horseback or camel cannot look into the interior, also no windows are situated so as to overlook the apartments of another house".

In houses with two storeys, windows on the second floor are very large and treated by shutters or latticed wood (Lane, 1838).

Morgan (1965) has mentioned that it is important to have a clear understanding of the purpose or function of the window. It is not only for ventilation, light and view, as it would be defined by an ordinary man who occupies a building. In order to assist him in forming his definition, it is necessary to review man's attitude to the sun. From the very beginning of time, man has had a subconscious or even perhaps a conscious appreciation that all life stems from the sun, hence the oldest form of worship was sun-worship. With the rising of the sun, each day had a new beginning and new purpose; man had a sense of well-being, of living, and his principal fear was the return of darkness.

"Deep in the psychological complex of man is the desire to be out in the open, free in the daylight, to be unconfined. The very antithesis of being free is to be incarcerated in a cell, the only contact with life-giving daylight a small barred prison window. To take away the window is to remove this contact with the life-giving source. Without it, there is death, if not to the body, certainly of the mind."
(Morgan, 1965).

It is generally agreed that the principle of thermal sun-control is to let the sun's energy into the building during the winter time and to intercept it in the summer time (Olgyay and Olgyay, 1976).

Several surveys have indicated that the desire for sun is very strong especially in housing, and this may be particularly so during the winter months. (Ritchie and Page, 1965).

The function of all window glass is to admit daylight into the building, but artificial light must always be complementary to daylight. (Morgan, 1965).

The window also has a great effect on ventilation for cooling the structure in hot arid zones which have high diurnal variations in temperature. In this section the effect of window size and its orientation on indoor temperature and the proportion of window size to ventilation rate for cooling the structure will be shown.

5.4.1 Influence of window size on indoor temperature

The amount of solar radiation which is received on a window surface depends mainly on its orientation, but the quantity of solar radiation which is transmitted to the interior wall depends on the incidence angle, the efficiency of shading and louver type outside the window.

To study the influence of the size of windows on indoor temperature, I used model (1) (Figure 5.1.1) with a 400 mm thick wall of limestone and windows in different sizes:

$$\text{Window 1} = 1.2 \text{ m}^2$$

$$\text{Window 2} = 3.6 \text{ m}^2$$

$$\text{Window 3} = 7.2 \text{ m}^2$$

$$\text{Window 4} = 10.8 \text{ m}^2$$

The window is assumed to have a 3 mm single, uncleaned pane without any treatment, or shaded externally, or with external blind.

In the case of shading it is assumed that the direct radiation is reduced according to shape of shading device, the diffuse radiation to 50%. For a venetian blind on the outside, the direct radiation will be reflected by 75% and absorbed in the blind by 25%. The diffuse radiation will be reflected by 35%, absorbed by 15% and transmitted by 50%.

If the window faces south or north, the area of window will be about

$(3.6 \text{ m}^2) = 1/3$ of the facade area

$(7.2 \text{ m}^2) = 2/3$ of the facade area

$(10.9 \text{ m}^2) = 3/3$ of the facade area

The maximum, minimum and mean room air temperatures in a room with a single glazed window facing south and treated externally by a venetian blind and with the room unventilated are shown in Table 5.4.1. The width of the window was varied from 1/3 to the full width of the wall area. In the first case the room has no windows.

It can be seen from Table 5.4.1 that even in a room without a window the maximum room air temperature is high. So are the minimum temperatures, but when the window size is increased, both minimum temperature and mean temperature decrease. This is caused by the lower thermal resistance of the window area compared with a wall, which helps to cool the room during the night time.

Table 5.4.1 Influence of window area facing south on room air temperature (window has a venetian blind).

Window area facade area	Room air temperature ($^{\circ}\text{C}$)		
	Maximum	Minimum	Mean
None	40.2	38.6	39.4
1/3	39.9	38.4	39.2
2/3	39.9	38.2	39.1
3/3	40.3	37.6	38.9

For windows without treatment or shading or with blind, a similar result is observed concerning the minimum room air temperature (Table 5.4.2). It decreases when the area of the south-facing window is increased. On the other hand, the maximum room air temperature increases with increased window area; with a window without treatment (with no solar protection) and 10.8 m^2 of glass area facing south, the maximum room air temperature will be as high as 42.9°C .

In Table 5.4.3 a comparison is made between west-facing windows with different areas and with different external treatments (by shading or blind). From Table 5.4.3 it can be seen that when the window area is 1.2 m^2 and untreated, the maximum room air temperature will be 41.5°C and minimum room air temperature 39.8°C . The floor surface temperatures will be 41.9°C and 40.1°C respectively.

When the window area is 10.8 m^2 and untreated, the maximum room air temperature will be 52.9°C , and minimum room air temperature will be 41.4°C . The floor surface temperatures will be 56.9 and 42.9°C respectively.

When the window has an area of 10.8 m^2 and is externally shaded, the maximum room air temperature will be 42.0°C and the minimum room air temperature will be 36.7°C . The floor surface temperatures will be 42.1°C and 38.9°C respectively. When the window is treated by external blinds, results are obtained which are similar to those mentioned for external shading.

This result means that increasing the window size facing west without treatment will increase the maximum and minimum indoor temperature, but by increasing the window size and using external treatment by shading or blinds only a slight increase in maximum indoor temperature and a decrease in the minimum indoor temperature are obtained.

5.4.2 Influence of window orientation

When a window has no shading, the amount of solar radiation entering through the window of glass depends mainly on the orientation of the window, which obviously influences the indoor temperature.

Table 5.4.3 Influence of window area facing west on maximum and minimum temperature of room air and internal surfaces.

Window size and external treatment	Room air temperature		Inside surface temperature (°C)																
			South			North		West		East		Roof		Floor		Window		Door	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
None	Window 1	41.5	39.8	40.7	39.2	41.1	39.5	41.6	39.8	41.4	39.8	42.1	39.5	41.9	40.1	47.9	28.9	43.9	37.4
	Window 2	45.0	40.6	43.7	40.7	44.1	40.9	43.9	41.3	44.7	42.4	44.5	40.8	46.4	41.4	49.3	29.2	47.8	38.1
	Window 3	49.3	40.7	47.6	41.7	47.9	41.9	47.5	42.6	48.7	42.1	47.7	42.1	52.1	42.2	50.9	29.4	52.8	38.4
	Window 4	52.9	41.4	50.9	42.3	51.4	42.5	50.7	43.6	52.1	42.7	50.5	43.0	56.9	42.9	51.4	28.8	57.7	38.8
External shade	Window 1	39.9	38.9	39.7	38.4	40.1	38.6	40.6	38.9	40.5	38.9	41.1	38.6	39.6	39.0	45.1	28.5	41.9	36.7
	Window 2	40.3	38.8	39.7	38.8	40.0	39.1	40.6	39.4	40.4	39.3	41.3	38.8	40.3	39.0	45.4	28.3	42.8	36.3
	Window 3	41.5	37.7	40.2	38.8	40.6	39.0	40.7	39.8	41.1	39.2	41.7	38.9	41.7	38.7	45.8	28.1	43.9	35.9
	Window 4	42.3	37.0	40.9	38.5	41.3	38.7	41.2	39.7	41.8	38.9	42.1	38.9	42.8	38.4	46.4	27.3	45.0	35.5
External blind	Window 1	39.9	38.9	39.7	38.1	40.0	38.4	40.6	38.7	40.4	38.7	40.9	38.5	39.5	38.7	45.6	32.9	41.6	36.6
	Window 2	40.1	38.9	39.7	38.4	40.0	38.7	40.6	38.9	40.4	38.9	41.1	38.6	39.6	39.0	45.9	32.9	42.2	36.5
	Window 3	40.7	38.1	39.4	38.3	39.7	38.6	40.3	38.9	40.2	38.8	41.0	38.4	39.9	38.5	46.2	32.4	42.6	35.9
	Window 4	41.1	37.9	39.7	38.3	40.0	38.6	40.3	38.9	40.6	38.8	41.1	38.3	40.4	38.3	47.2	31.8	43.1	35.5

The thermal effect of window orientation, window size and external treatment of the window are shown in Figure 5.4.1. It can be seen that when the window is in a westerly direction and without treatment, the maximum temperature of the room air increases sharply with increasing window area: when the window is about 10% of the wall area the maximum room air temperature will be about 6.0 °C lower than maximum outdoor temperature (47.2 °C), but when the window area covers nearly the total facade, the maximum room air will be 5.6 °C above outdoor temperature. When the window is externally shaded or has an external blind, the maximum room air temperature increases only slightly.

When the window faces east and is externally untreated, the maximum

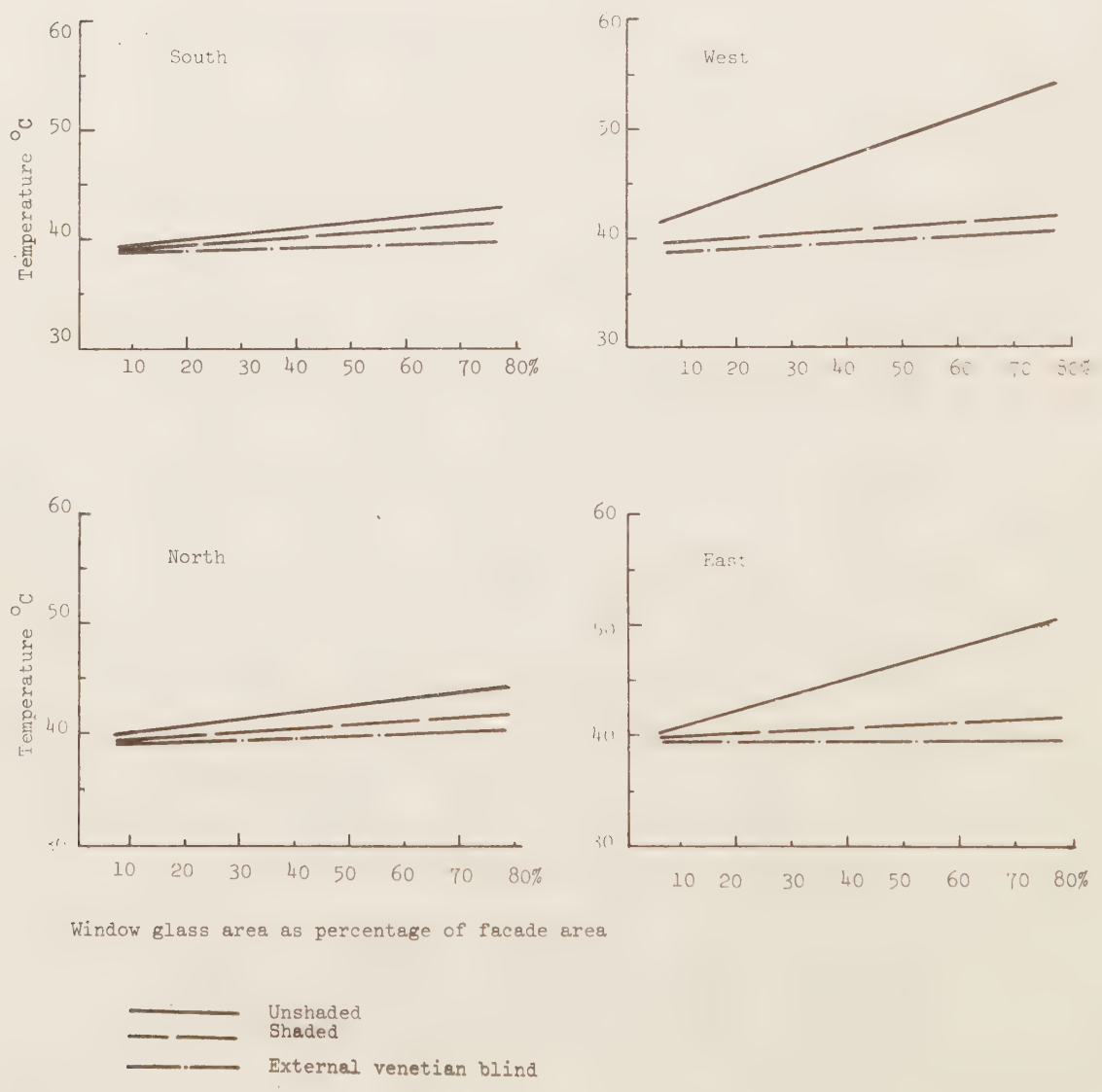


Figure 5.4.1 Influence of window glass area on maximum room air temperature with different orientations.

room air temperature will be about 6.5°C lower than the maximum outdoor temperature and when the window covers nearly the facade the maximum room air temperature will be 5°C above outdoor temperature. When the window is shaded or has an external blind, a slight effect of the window (glass) area on the maximum room air temperature can be seen.

When the window faces south and is untreated externally, the maximum room air temperature will be 7.3°C lower than the maximum outdoor temperature; when the window area is about equal to the full area of the facade, the maximum room air temperature will be 4.3°C lower than outdoor temperature, but when the window is externally shaded or treated by external blind, the increase in the maximum room air temperature is insignificant.

From Figure 5.4.2 it can be seen that when a window facing west is externally untreated, increased glass area will result in an increased maximum and minimum room air temperature. When the window faces south, increasing its area will cause only a slight increase in maximum room air temperature and a decrease in minimum room air temperature.

This results mean that when a window is externally untreated, its orientation has a decisive effect on indoor temperature. When the window is treated externally by any shading device, the orientation has only a slight effect on indoor temperature, dependent on the shading type.

The lowest indoor temperature during summer time can be obtained when the window faces south. The advantage is that the sun's rays penetrate into the room in winter but not in summer because of the vertical path of the sun.

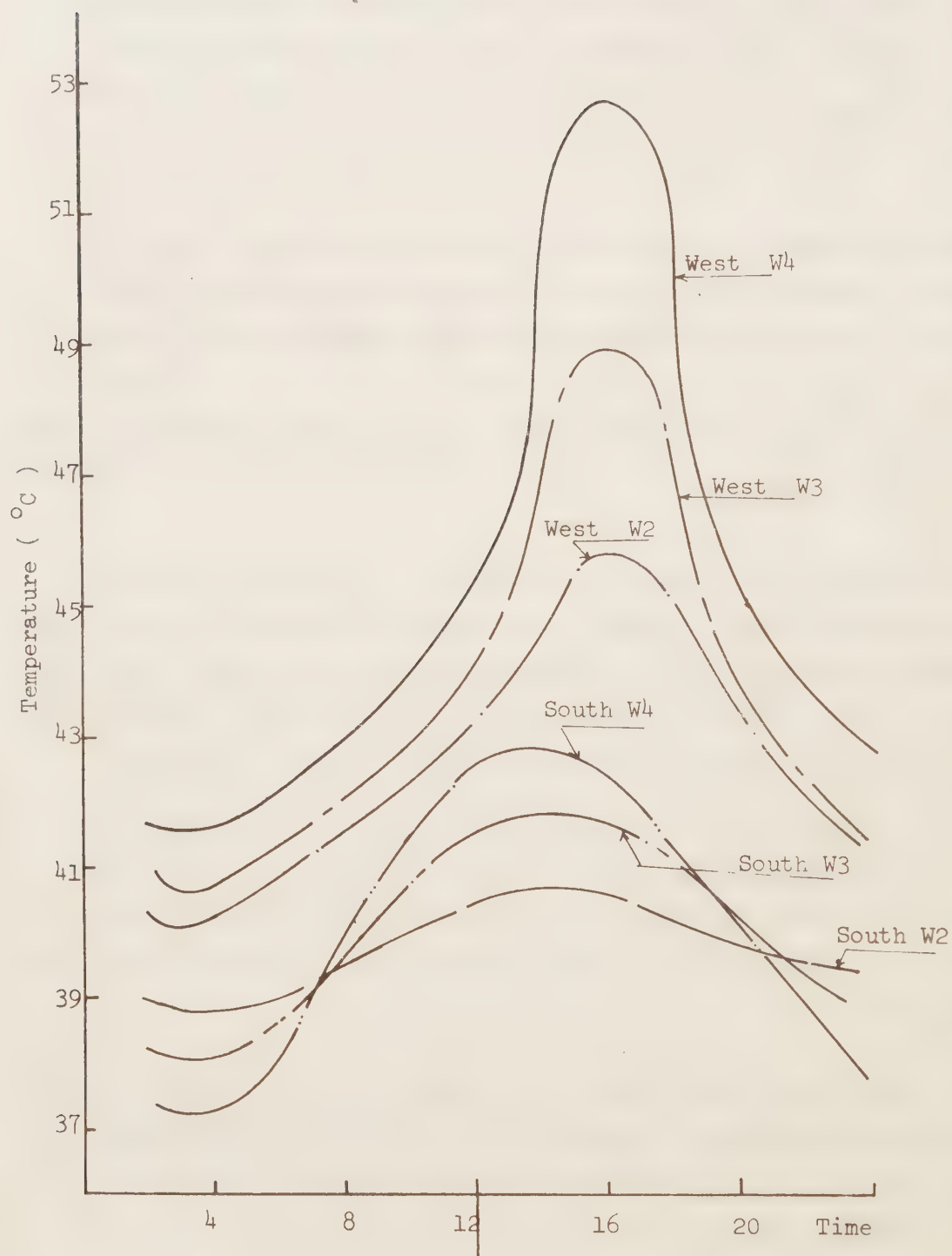


Figure 5.4.2 Influence of window area and orientation on room air temperature. Comparison between windows facing west and south with different areas, $W2=3.6 \text{ m}^2$, $W3=7.2 \text{ m}^2$ and $W4=10.8 \text{ m}^2$ glass.

5.4.3 Influence of window size in combination with night ventilation of the room

The amount of solar radiation which heats the interior of the room is proportional to the area of the window. If natural ventilation is applied for cooling the structure at night, when the outdoor temperature is low as in the hot arid zone, the efficiency of ventilation is also proportional to the area of the window.

The influence of the ventilation rate and window area on indoor temperature are shown in Table 5.4.4. When the room is ventilated at night, the window area has a remarkable effect on the minimum room air temperature. When the window area is 3.6 m^2 and the ventilation rate at night is 2.5 air changes per hour, the minimum room air temperature is 34.2°C but if the window area and ventilation rate are doubled, the minimum room air temperature will be not more than 31.4°C . This is not only because of increased ventilation rate through the larger window, but also because of the heat losses through the window area.

It is evident that solar heat gain through a glass area is higher than through an equal area of a massive wall, but when external shading is applied to the window, it will reduce the solar heat gain. If natural ventilation is required for cooling the structure at night, when the outdoor temperature is lower than the indoor temperature, the ventilation rate for cooling the structure is proportional to the window area.

Therefore, in designing a window for a hot arid zone, one must first consider the window area so that it gives a maximum ventilation rate for night cooling of the structure. The window must then be treated externally by a solar shading device to prevent the solar radiation from penetrating into the building but allowing transmission of enough daylight to light the interior.

In old traditional building (Islamic houses, see Figures 4.3.12-14) it can be seen that on the second floor the window usually covers the full area of the wall, is treated externally with latticed wood, and faces north to catch the northern breeze.

Table 5.4.4 Influence of window area and ventilation rate at night on room air and internal surface temperature.
Window facing west and externally shaded. Walls made of 400 mm limestone.

Window type and ventilation conditions	Internal surface temperature (°C)											
	Room air temperature		South		North		West		East		Roof	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Window 2 Unvent.	40.3	38.6	39.7	38.8	40.0	39.1	40.6	39.4	40.4	39.3	41.3	38.8
Window 2 v=2.5	40.0	34.2	38.6	37.2	38.9	37.5	39.0	38.1	39.5	37.7	40.3	37.7
Window 3 Unvent.	41.5	37.7	40.2	38.8	40.6	39.0	40.7	39.8	41.1	39.2	41.7	39.0
Window 3 v=5	40.2	31.4	39.2	36.1	39.5	36.3	39.4	37.0	40.0	36.5	40.5	37.3
											40.3	35.6
											45.4	28.3
											44.9	27.1
											45.8	28.1
											45.3	26.5
											42.8	42.8
											42.2	42.2
											44.0	44.0
											35.9	35.9
											43.2	43.2

The ventilation rate (airchanges/hour) is assumed double the value of the window area (m²). Night ventilation between 1900 (7 p m) and 0800 (8 a m).

5.5 INFLUENCE OF SHAPE AND VOLUME OF ROOM ON INDOOR AIR TEMPERATURE

The form of a building can be designed in relation to the climatic zone. In a hot climate, the old traditional building creates comfortable conditions in internal space by adjustment of the internal volume of the room to comfort requirements through use of external space between or around the building as a courtyard - an open space which can function especially as an extension of living space.

This study concerns the internal space which determines the volume of the room in two aspects:

First, the ratio of the volume of the room to the surface area which is exposed to the external environment, hot during the day and cold at night and with large diurnal temperature variations.

Second, the depth or distance between opposing surfaces. When the room has two open facades, air movement is very important for cooling the internal surfaces at night.

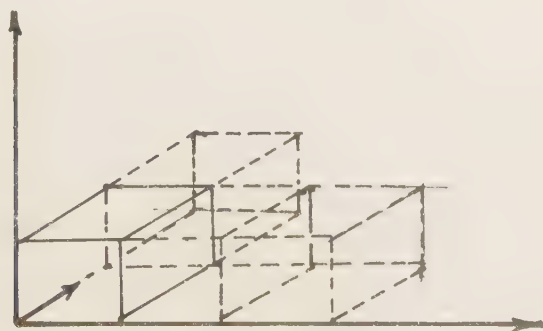
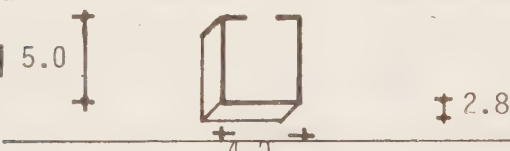
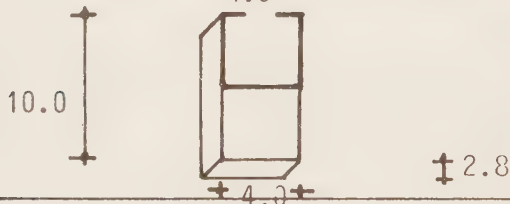
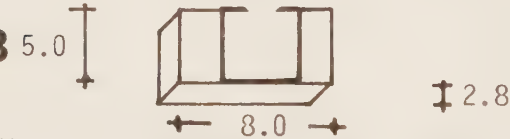
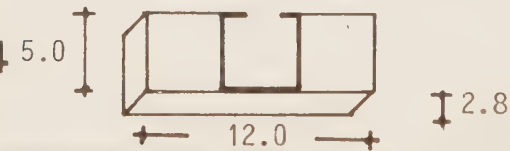


Figure 5.5.1 Room dimensions expanded in two directions.

Therefore, I have studied model (1) which has a volume of 56 m^3 and is 4.0 m wide, 5.0 m long and 2.8 m high. These dimensions can be extended on two axes by doubling the distances (see Figure 5.5.1). Consequently shapes 2, 3 and 4 will be obtained with different volumes and aspect ratio (ratio of surface area/volume of the room) as seen

in Table 5.5.1. The reason why the room is not expanded in height is that in a high room the room air will be stratified and the assumption of equal room air temperature, made in the simulation program, will not be valid.

Table 5.5.1 Relationship between surface area (A) and volume (V) - the aspect ratio. The window is always facing north.

Shape		Surface area $A(m^2)$	Volume $V(m^3)$	Aspect ratio $A/V(m^{-1})$
1		90.4	56	1.164
2		158.4	112	1.414
3		152.8	112	1.364
4		215.2	168	1.281

Obviously a larger room height can create better conditions for the occupants in hot climates.

First, with higher ceilings less radiation will be transmitted to the occupants, because the solid angle (view factor) of the ceiling experienced by the occupant will be less than with a lower ceiling.

Second, heated air will form a layer under the ceiling which in the

case of a high ceiling will be above the heads of the occupants.

The ratio of the volume of the room to the surface area also depends on the dimensions of the room. From Table 5.5.1 it can be seen that shape 2 and shape 3 are equal in volume but have different surface areas, thus giving different aspect ratios (A/V). The lowest ratio will be obtained with a cube shape.

The following section will show the influence of the room volume on indoor temperature with regard to the heat capacity of the wall, characteristics of external surfaces and the ventilation conditions of the room.

5.5.1 Effect of the heat capacity of the wall

The effect of volume and heat capacity of the walls on indoor temperature depends mainly on the quantity of heat which is stored on the wall during the daytime and the speed with which it is dissipated during the night-time.

By comparing a room with a volume of 56 m^3 and one with a volume of 112 m^3 with different heat capacity, it can be seen (Table 5.5.2) that when the wall is 100 mm thick, increasing the volume has no significant effect on the maximum indoor temperature, but increasing the volume of the room will slightly elevate the minimum indoor temperature. When the wall is 400 mm thick, increasing the volume of the room has a noticeable effect on indoor temperature. When the volume is 112 m^3 (shape 2), maximum air temperature will be 0.5°C and minimum air temperature will be 0.2°C higher than the maximum and minimum room air temperature of the room with a volume of 56 m^3 (shape 1).

5.5.2 Effect of external surface characteristics on different shapes

It is evident that the larger the volume of a room, the larger the surface exposed to the external environment. The ratio between heat

Table 5.5.2 Influence of volume and heat capacity of room on indoor temperature. Comparison between Shape 1 and Shape 2.
Walls are made of stone, 100 and 400 mm thick.

Volume and shape of room	Thickness of walls	Room air temp.	Inside surface temperature (°C)																	
			South		North		West		East		Roof		Floor		Window		Door			
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
1		100	45.4	33.2	45.2	31.5	46.4	31.6	49.8	31.7	45.9	31.6	42.9	37.1	42.2	35.5	44.5	30.4	45.6	32.5
		400	39.8	38.7	39.6	38.1	40.0	38.3	40.5	38.7	40.4	38.6	40.9	38.4	39.5	38.7	42.5	33.0	41.5	36.6
2		100	45.4	34.0	45.2	32.0	46.4	32.1	49.7	32.2	45.9	32.1	43.0	37.5	42.3	36.2	30.9	38.0	45.5	33.1
		400	40.3	38.9	39.9	38.3	40.3	38.6	40.8	38.9	40.7	38.9	41.1	38.7	39.8	38.9	42.7	33.3	41.7	36.9

Outdoor air temperature: Max=47.2 $^{\circ}\text{C}$, min=21.6 $^{\circ}\text{C}$.

gain by the surface to heat losses depends on the diurnal range of the outdoor temperature and on the quantity of incident solar radiation. This is determined by room orientation and the treatment of external surfaces. Table 5.5.2 showed a comparison between a room with a volume of 56 m^3 and one with a volume of 112 m^3 ; the difference is caused by increasing the volume through increasing the depth of the room in north-south direction. It can be seen that maximum and minimum indoor temperature increase with increasing volume of the room.

However, if the volume of the room is increased by increasing the depth in an east-west direction (Table 5.5.4), the indoor temperature will slightly decrease.

When external surfaces are treated by shading or by white colours, the indoor temperature can be reduced. From Table 5.5.3, it can be seen that, when the volume is 56 m^3 (shape 1), the maximum room air temperature with unshaded surfaces will be 39.8°C . When the volume is 112 m^3 (shape 3), it will be 39.7°C . The minimum room air temperature will be 38.7°C and 38.3°C .

If the east and west surfaces are shaded, the maximum room air temperature will be 38.0°C and 37.6°C and minimum room air temperature will be 37.0°C and 36.1°C for shapes 1 and 3 respectively.

This result means that increasing the volume of the room can slightly reduce indoor temperature and that this rate of reduction is increased when external surfaces are treated by shading.

5.5.3 Effect of ventilation for cooling in different shapes

The relationship between volume of room and ventilation conditions has been examined by comparing rooms with volumes of 56 m^3 , 112 m^3 and 168 m^3 , unventilated or night-ventilated with 1.6 air changes per hour.

Table 5.5.3 Influence of volume and shaded external surfaces on indoor temperature. Comparison between shape 1 and shape 3.
The walls are made of 400 mm limestone.



Volume and shape of room	External surfaces condition	Room air temp	Inside surface temperature (°C)																
			South		North		West		East		Roof		Floor		Window		Door		
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
v=56 m ³ , shape 1 	Unshaded	39.8	38.7	39.6	38.1	40.0	38.3	40.5	38.7	40.4	38.6	40.9	38.4	39.5	38.7	42.5	33.0	41.5	36.6
	Shaded (E,W)	38.0	37.0	38.1	36.7	38.5	37.0	37.9	36.6	38.0	36.6	39.5	37.1	37.8	37.1	41.1	31.9	40.1	35.1
v=112 m ³ , shape 3 	Unshaded	39.7	38.3	39.4	37.8	38.8	38.1	40.3	38.4	40.2	38.4	40.7	38.2	39.3	38.4	42.3	32.9	41.3	36.4
	Shaded E,W	37.6	36.1	37.8	36.2	37.2	36.6	37.4	36.9	37.4	36.2	39.2	36.7	37.4	36.7	41.1	30.7	39.8	34.9

Outdoor air temperature: max = 47.2 °C, min = 21.6 °C.

From Table 5.5.4 it can be seen that in an unventilated room with a volume of 56 m^3 , maximum room air temperature will be 7.4°C lower than maximum outdoor temperature; when the room has volumes of 112 m^3 and 168 m^3 , it will be 7.5°C and 7.7°C respectively.

When the room is ventilated at night with volumes of 56 m^3 , 112 m^3 and 168 m^3 , maximum room air temperature is lower than outdoor temperature by 9.5 , 10.1 and 10.4°C respectively.

This means that increasing the volume of a room by increasing the depth in an east-west direction can lower indoor temperature. This rate can be increased by ventilating the room at night.

Table 5.5.4 Influence of volume and ventilation conditions on indoor temperature. Comparison between room 4x5x2.8, 8x5x2.8 and 12x5x2.8 in case of unventilated and night-ventilated with 1.6 air changes per hour.

Volume and shape of room	Ventilation conditions	Room air temp	Inside surface temperature (°C)																
			South		North		West		East		Roof		Floor		Window		Door		
			Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
 $v=56\text{ m}^3$	Unvent.	39.8	38.7	39.6	38.1	40.0	38.3	40.5	38.7	40.1	38.6	40.9	38.4	39.5	38.7	42.5	33.0	41.5	36.6
	Night vent.	37.7	31.9	37.1	35.9	37.4	36.3	37.6	36.7	37.9	36.5	39.0	36.4	37.1	35.5	41.3	29.9	39.9	33.3
 $v=112\text{ m}^3$	Unvent.	39.7	38.3	39.4	37.8	39.8	38.1	40.3	38.4	40.2	38.4	40.7	38.2	39.2	38.4	42.3	32.9	41.3	36.4
	Night vent.	37.1	30.9	36.7	35.5	37.0	35.8	37.2	36.2	37.6	35.9	38.6	36.7	34.9	40.9	29.5	39.5	32.7	
 $v=168\text{ m}^3$	Unvent.	39.5	38.0	39.2	37.7	39.6	37.9	40.2	38.3	40.0	38.3	40.5	38.1	39.2	38.2	42.2	32.8	41.2	36.3
	Night vent.	36.8	30.4	36.5	35.2	36.8	35.5	37.1	36.0	37.4	35.8	38.4	35.8	36.6	34.8	40.8	29.3	39.4	32.5

Outdoor air temperature: max = 47.2 °C, min = 21.6 °C.

6 NATURAL VENTILATION AND AIR MOVEMENT IN BUILDINGS

There are several functions of ventilation, which may be summarized in two main factors: for health, which is determined by the provision of sufficient oxygen and the removal of body and other odours, and for thermal comfort, which is determined by the removal of excess heat, air movement for body cooling, and cooling of the structure which surrounds the body.

6.1 HEALTH VENTILATION REQUIREMENT

The first function of ventilation is to replace the used internal air with fresh external air. Minimum ventilation is required for this purpose in all occupied dwellings. The relation between recommended ventilation requirements and air space per person is given in Figure 6.1.1, (Straaten, 1967).

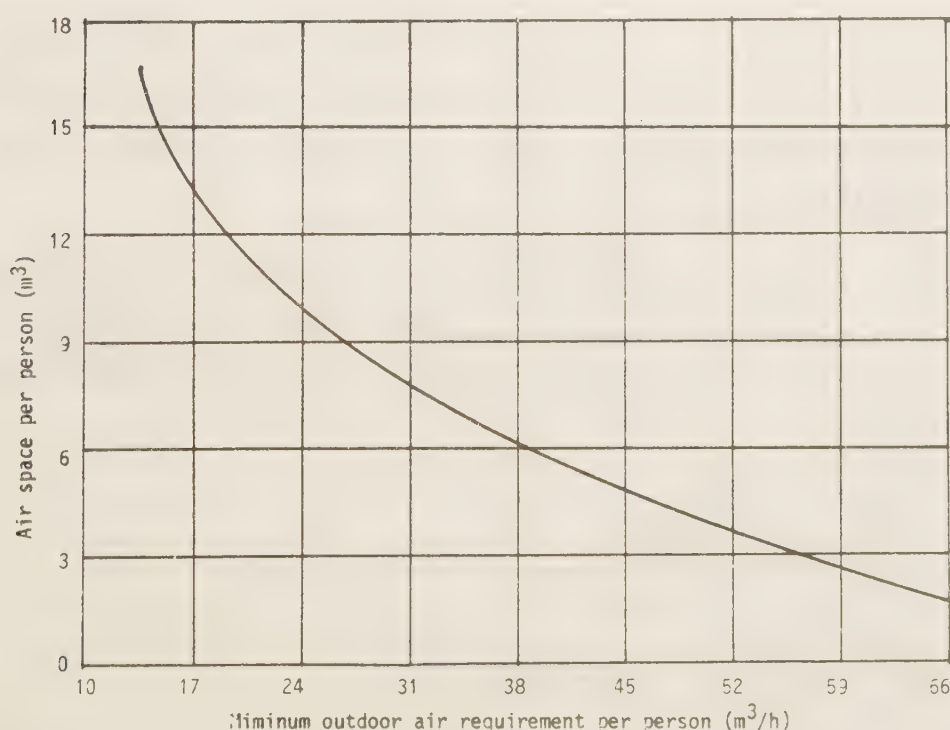


Figure 6.1.1 Minimum desirable ventilation requirements for unconditioned buildings. (Straaten, 1967).

It can be seen that the quantity of air per person is decreased as space per person is increased. This explains why in old, traditional buildings the main room for summer use is very large. It is kept closed (unventilated) during the daytime, when the outdoor temperature is very high. During the night the used internal air is replaced by fresh external air for use the next day.

6.2 MECHANISM OF NATURAL VENTILATION

Air moving into, through and out of a building naturally can be the result of wind force or thermal force, which is determined by temperature differences outside and inside the building, or of a combination of the two, depending on building design and location and atmospheric conditions. However, wind force is the most important and it is better if the processes act cooperatively, not in opposition. (Ashrae, 1970).

6.2.1 Air flow due to wind forces

If natural wind forces are to be used for ventilation, the average wind velocity and the direction of the prevailing wind must be taken into consideration - the prevailing wind direction in Aswan is usually north or northwest.

According to the Ashrae Handbook (1970), the quantity of air forced through a ventilation opening by the wind, as well as the proper size of such openings to produce a given result, can be calculated from the following:

$$Q = E \cdot A \cdot v \quad (6.2.1)$$

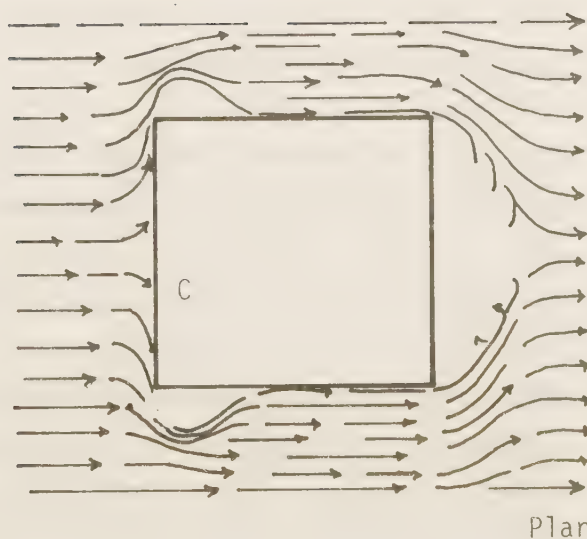
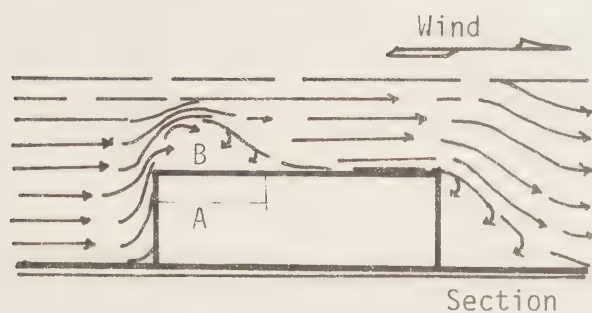
where Q = air flow, m^3/s

A = free area of inlet opening, m^2

v = wind velocity, m/s

E = effectiveness of opening, should be taken at 0.5 to 0.6 for perpendicular winds, and 0.25 to 0.35 for diagonal winds.

Inlets should be placed to face directly to the prevailing wind, while outlets should be placed on the side of the building opposite the direction of the prevailing wind, or in the roof in a suction area (Figure 6.2.1). (Ashrae, 1955).



A= length of section area
 B= point of maximum intensity of suction
 C= point of maximum pressure

Figure 6.2.1 The path of wind around a building. (Ashrae, 1955).

6.2.2 Air flow due to temperature difference (stack effect)

When the temperature in a building or room is different from the outside temperature, pressure differences between inside and outside occur as a result of differences in air density, that is, chimney or stack effect.

According to the Ashrae Handbook (1970), "The importance of maintaining the greatest possible height between inlets and outlets is obvious". This explains why old houses have high ceilings. The height can be more than 6 meters, see Figures 4.4.3b and 4.4.7 in chapter 4.

6.2.3 Air flow due to combined wind forces and stack effect

When both forces are acting together, even without interference, the resulting air flow is not equal to the sum of the two estimated quantities. The flow through any opening is proportional to the square root of the sum of pressure acting on the opening. When the two heads are about equal in value, and the ventilating openings are operated so as to coordinate them, the total air flow through the building is about 10 per cent greater than that produced by either head acting independently under conditions ideal to it. (Heating, ventilating and air conditioning guide, 1960).

According to Ashrae (1970) the distribution of indoor and outdoor pressures with height for a building in which openings of equivalent area are equally distributed above and below mid-height and where there is no significant flow resistance inside (Figure 6.2.2).

The slopes of the lines are functions of the densities of indoor and outdoor air. In Figure 6.2.2a where the inside is warmer than outside and only pressure difference due to stack effect is acting, the neutral zone is at mid-height with flow-in through all openings below and flow-out through all openings above the neutral zone. Figure 6.2.2b shows pressure differences due to the wind alone with the flow-in volume due to wind effect on windward side equal to the flow-out volume on leeward sides. Figure 6.2.2c represents the condition where the wind forces

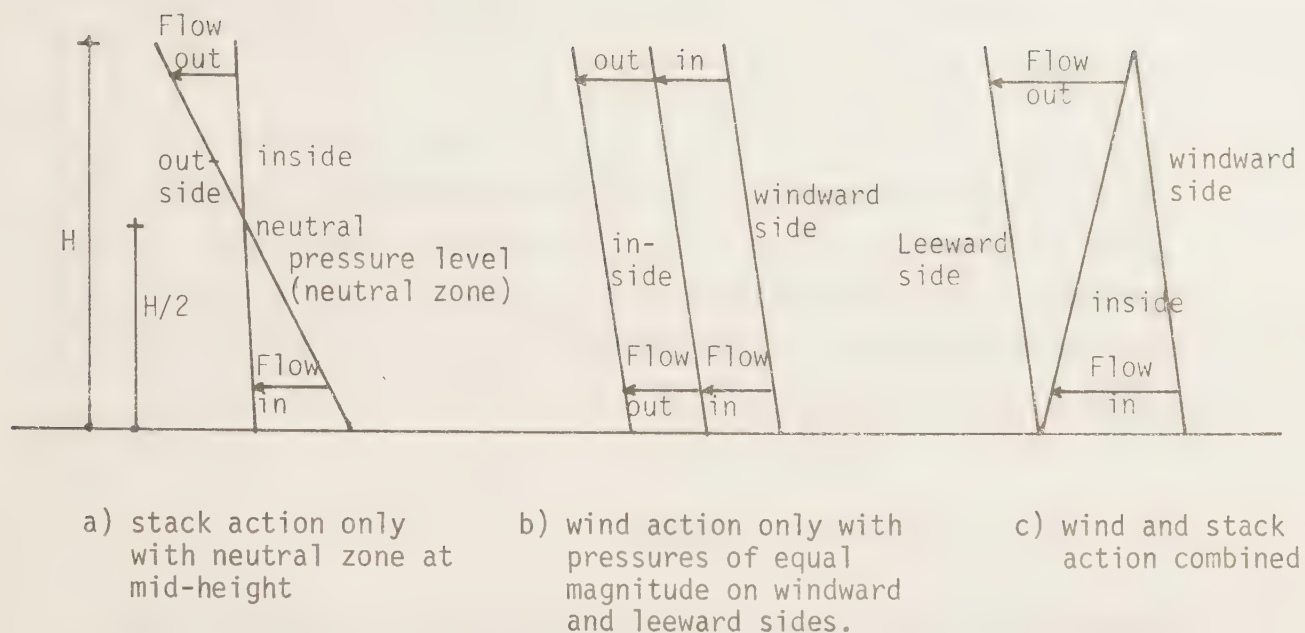


Figure 6.2.2 Distribution of inside and outside pressures (Ashrae, 1970).

illustrated in Figure 6.2.2b have just balanced the temperature difference forces with no pressure difference at the top on the windward sides or at the bottom on the leeward sides. Thus the total flow is only slightly more than wind action alone. For the specific case illustrated in Figure 6.2.2c the pressure differences created by wind and those due to temperature difference acting solely can be added to determine the combined effect.

Ventilation of the room by stack effect (thermal force) depends mainly on two factors: temperature difference between outdoors and indoors, and vertical distance between inlet and outlet (height of the ventilation path). One-storey buildings usually have a small effective height for ventilation, the thermal force needs a certain difference between outdoor and indoor temperatures. Large differences in temperatures occur in cold climates. In hot climates the ventilation of the dwelling by thermal force is achieved in kitchens or bathrooms and toilets, which usually are ventilated by a shaft through several stories, creating a

large height for the ventilation path (Koenigsberger and Ingersoll, 1974). Stack effect can also be used in night-ventilated buildings where a temperature difference between inside and outside of about 5 °C can be achieved (Table 6.5.1).

It is preferable to achieve ventilation by both thermal force and wind force. For this combined air flow old traditional buildings had a wind catch on top of the roof to deflect the wind into the interior. There was also an opening in the roof in the low pressure area to remove hot air under the ceiling by stack effect (see Figures 4.4.1 and 4.4.3b in chapter 4).

6.3 VENTILATION FOR SUMMER COMFORT

As mentioned before, sensations of warmth and cold depend mainly on air movement (see chapter 3). Evans (1980) says "The ventilation must result in air movement at a sufficiently fast speed to be felt at body level. If the ventilation is not felt, it is not providing effective cooling. The cooling effect is not due to coolness of the air, but to the cooling effect of the velocity of the air as it increases evaporative and convectional heat loss."

Table 6.3.1 shows the wind speed which is effective for body cooling.

Table 6.3.1 Wind speeds and their effect (Evans, 1980)

Description	Speed m/s	Effect on man
Calm	0 - 0.5	none
Light air	0.6 - 1.5	movement just perceptible due to cooling effect
Light breeze	1.6 - 3.3	cool air felt on the face
Gentle breeze	3.4 - 5.4	hair is disturbed, light clothing flaps, discomfort starts

Study of natural ventilation for cooling mostly concerns thermophysical properties of materials, which were studied previously, and air movement. We are here concerned with air movement in two main considerations for ventilation: air flow pattern and air flow speed inside the room.

It is obvious that air movement is essential for comfort during warm weather; The occupants should be in the breeze, not below it. However, the comfort of the occupants is not a result of the number of air changes per hour, but of an air movement where the occupants are sitting. Therefore, it is important to consider the air flow pattern, not air changes only.

6.3.1 Air flow pattern

In general, if air movement is to be achieved through a room, there must be an opening to let the air out as well as an opening to let the air in. The position and size of outlets and inlets affect the air flow pattern. The inlet should be placed to face directly into the prevailing wind. The inlet opening should be in high pressure regions and the outlet opening must be in low pressure regions. (Reed, 1952).

Caudill (1952) has pointed out that ceiling height (low or high) does not affect air flow pattern through a room, but the shape of the ceiling does affect the air flow pattern somewhat, depending on the exact ceiling profile. In old traditional buildings the domed and vaulted roofs give completely different air flow patterns than flat roofs.

However, "Ventilation in a vertical direction has its limitations in practice, the main disadvantage being from the point of view of air movement." (Straaten, 1967).

Openings can also be placed in the roof which has the further advantage that they are very effective for removing the layer of hot air below the ceiling.

6.3.2 Air flow speed

In order to provide movement of air through a room, there must be outlet and inlet openings, and to obtain maximum speed within a room, the outlet opening should be larger than the inlet, a very large inlet opening and a very small outlet opening will produce very slow air movement within a room (Reed, 1952 and Givoni, 1976).

The greatest number of air changes per square meter in relation to the openings is acquired when the inlets and outlets are equal in size and the maximum total volume or the greatest total number of air changes is acquired when both the inlet and outlet are as large as possible. (Reed, 1952).

Landsberg (1978) says that, "In a hot area that has low wind speed, if the housing is misplaced with respect to the wind, there will be insufficient ventilation." However, in Egypt a special opening for ventilation, "malkaf" (wind catch), has been used since 4000 B.C. (Caudill, 1951) to ventilate the indoor space below. The following section will show the function of the wind catch and the air flow pattern indoors in an experimental study which was carried out by the author in a wind tunnel at Chalmers Tekniska Högskola, Gothenburg.

6.4 DESIGN OPENING FOR AIR MOVEMENT AND EVAPORATIVE COOLING

6.4.1 Wind catch

Usually a window serves three main purposes in most climatic regions: it lets air in, it lets light in, and it lets people see out. These three functions are not inseparable. In old traditional buildings in hot climates the air movement influences the indoor environment and has a cooling effect by increasing the rate at which perspiration evaporates. Therefore, in a hot climate, builders made a special opening for ventilation separated from the other window functions.

The prevailing wind in Egypt is from the north-northwest and is rela-

tively cool. In urban areas wind catches on the roofs ("malkaf") are used to bring the wind down into the buildings. These devices are similar to ventilators on a ship. They are made of mud brick projected above the roof (see chapter 4, Figures 4.1.2, 4.4.1, 4.4.2a.b).

In old traditional planning the street was narrow to reduce the quantity of solar radiation falling on the surfaces of the building and the wind catch was formed to be a suitable device for ventilation. The wind catch is an interesting alternative for both single-storey and multi-storey buildings for ventilation by wind force, especially when city planning calls for narrow streets.

In the experimental study, I have compared the air flow in a model room with a wind catch on top of the roof in different positions (see Appendix B) with air flow in a room without wind catch, Figure 6.4.1, which is taken from Reed (1952). It can be seen from Figure 6.4.1 that, when the room is on the top floor of a two-storey building, that under iso-thermal conditions, the air flow will occur mostly above the living zone. Reed says, "This is caused by the inequality of pressures above and below the inlet openings as a result of their location in regard to the proportion of solid wall surface around the opening."

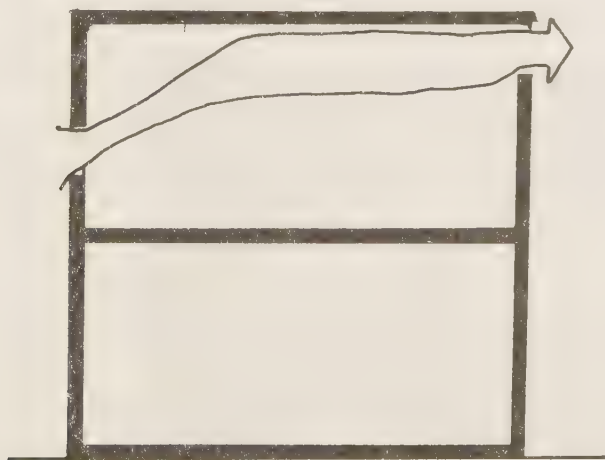


Figure 6.4.1 Air flow at second floor.

When wind catches are used (Figures 6.4.2-6.4.7), the air flow takes place in the living zone.

Position of the wind catch and windows

When the room has a wind catch in the middle of the roof (Figure 6.4.2) there is a slight air movement in the room which is perhaps insufficient for summer cooling. When the wind catch is perpendicular to the long axis of the room (Figure 6.4.3), the air flow inside the room is effective and washes the inside surfaces of the room, which can be of assistance in cooling the surfaces rapidly.

When the wind catch and a window are placed in the same direction as the wind, but the outlet window covers the full area of the wall, the air flow can reach all the room space (Figure 6.4.4). When the window is only $1/3$ as large as the wall area and placed near the floor, movement of hot air under the ceiling will be slow (Figure 6.4.5). Therefore, an opening in the roof in the suction area should remove the hot air under the ceiling. The best arrangement for getting the best air flow pattern into the space is to make the inlet and outlet as large as possible. Figure 6.4.6 shows that when the wind catch is placed on the windward side of the roof the wind can be deflected into the room before it passes over the roof surface. This case is better than the case in Figure 6.4.4, where the air passes over the roof surface, which warms it before it enters the interior.

In the case of a room where it is undesirable to make any window on the facade, two wind catches can be used (Figure 6.4.7), one toward the wind and the other toward the leeward, to permit air movement inside the room.

6.4.2 Evaporative cooling and fountains

If a comfort range for the occupants is not obtained by the thermal capacity of the wall and roof or by ventilation, evaporative cooling is an alternative. Of course, water must be available.

There are several devices to cool the air by drawing it under ground or through the basement (Saini, 1973). Cooled air can be produced by dampening a woven mat or straw mat which is hung in front of a window,

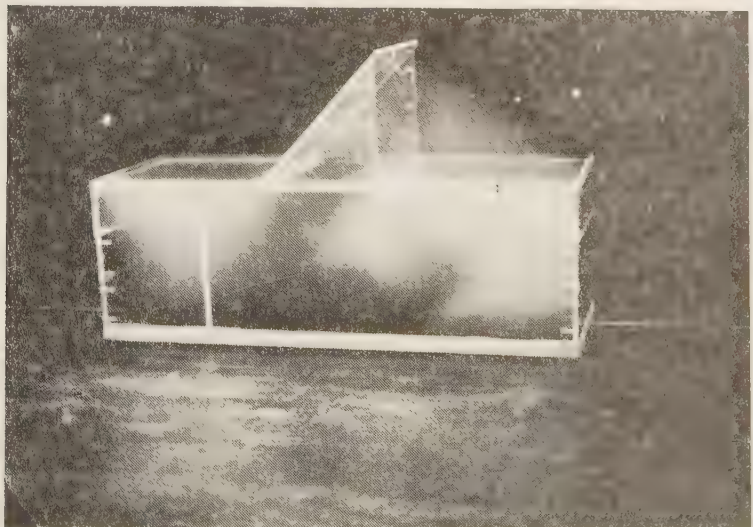
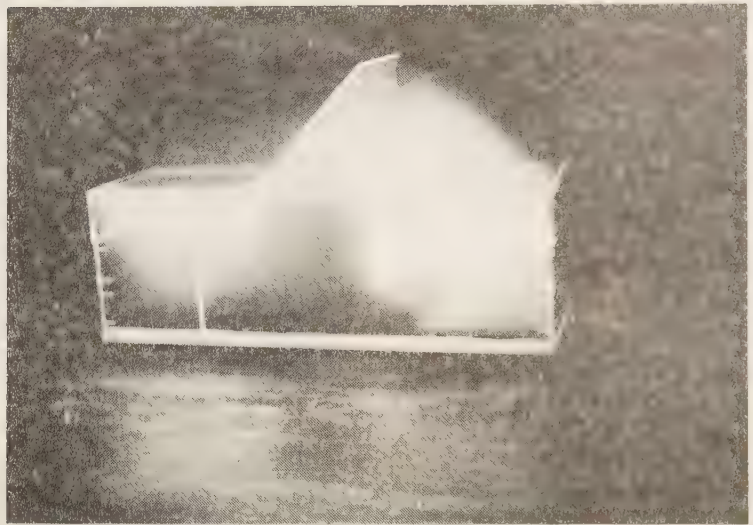


Figure 6.4.2 If the room has no window in the external wall and has only a wind catch in the middle of the roof, there is slight air movement in the room which is too little for summer cooling.

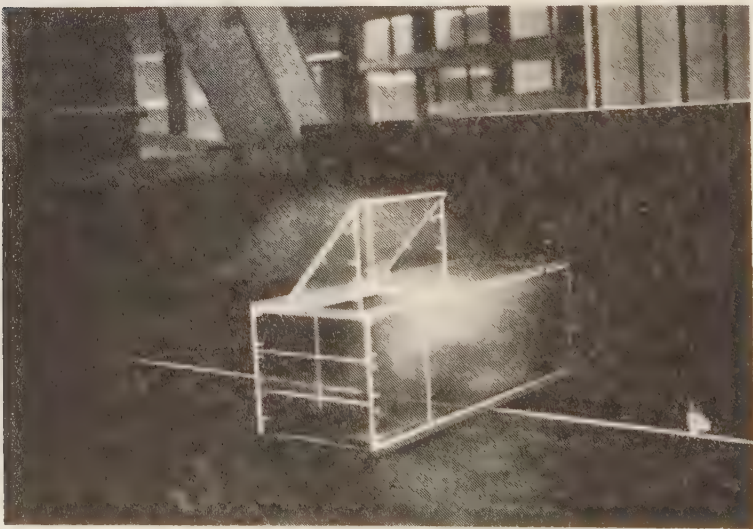
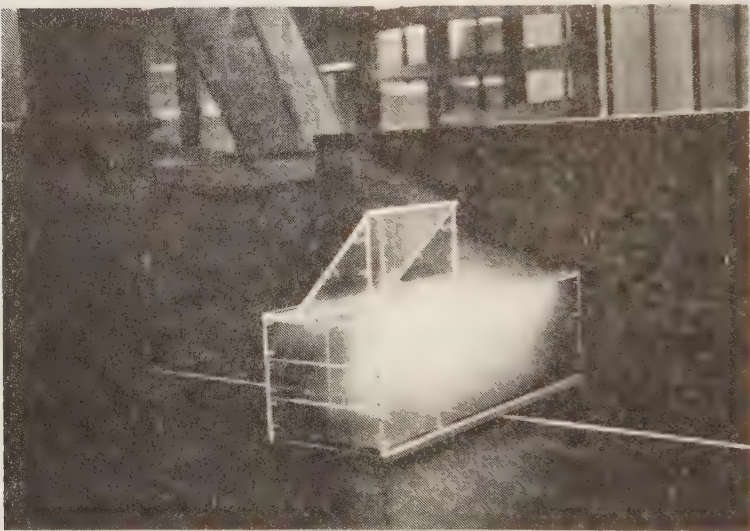
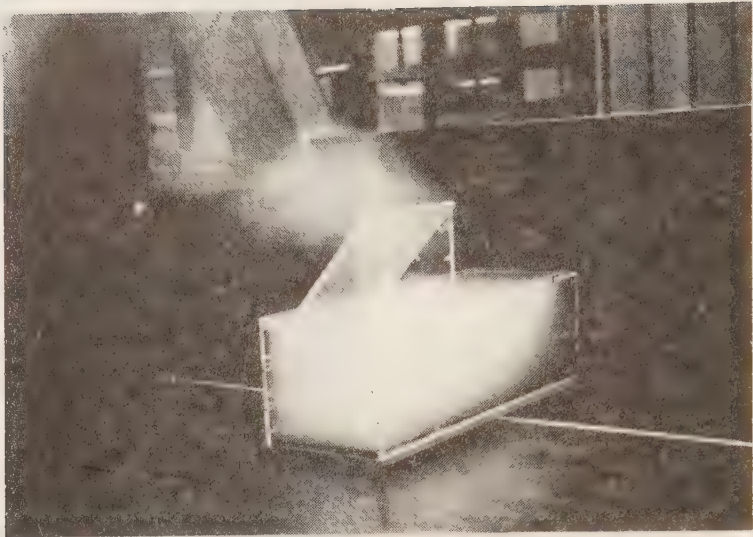
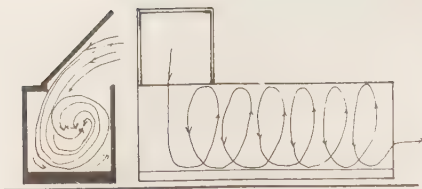


Figure 6.4.3 When the direction of the wind catch is perpendicular to the long axis of the room the air flow will be effective.

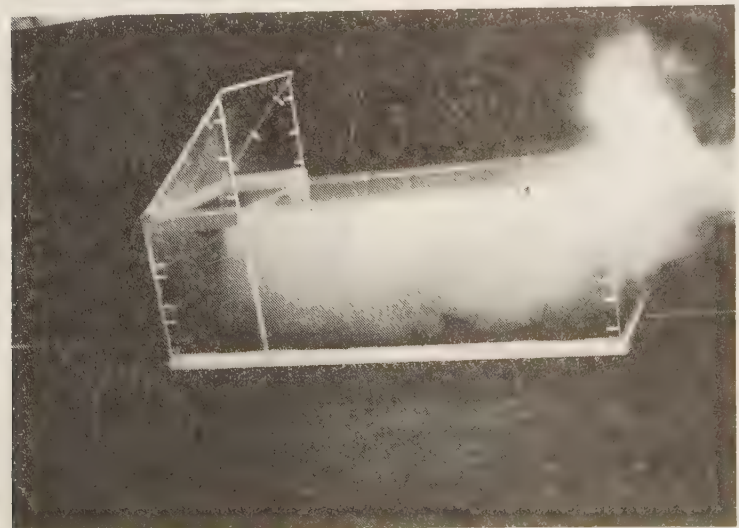
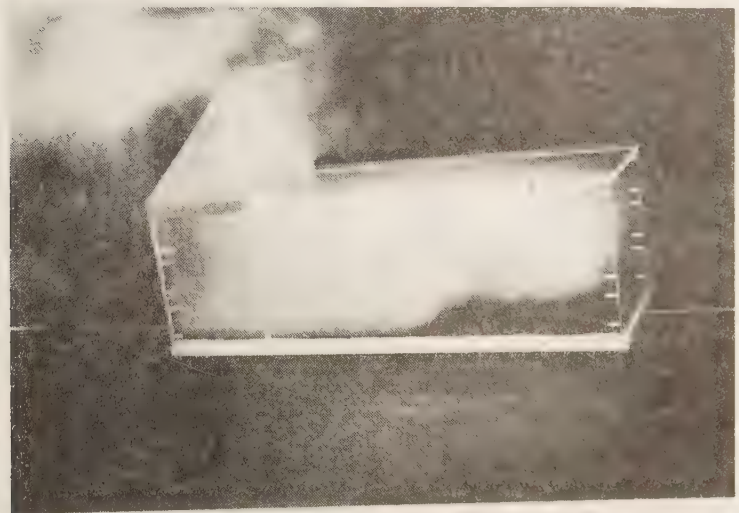
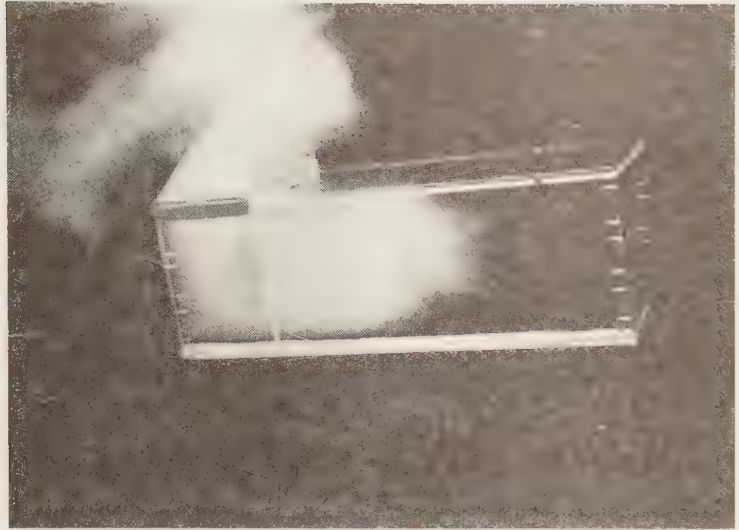
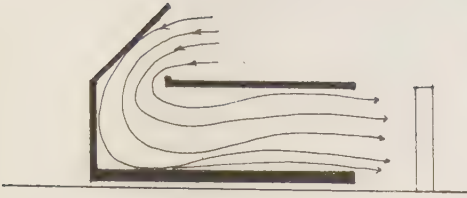


Figure 6.4.4 When the wind catch and windows are in the same direction and the window is in a low-pressure area, the air flow pattern will cover all indoor surfaces and remove air.

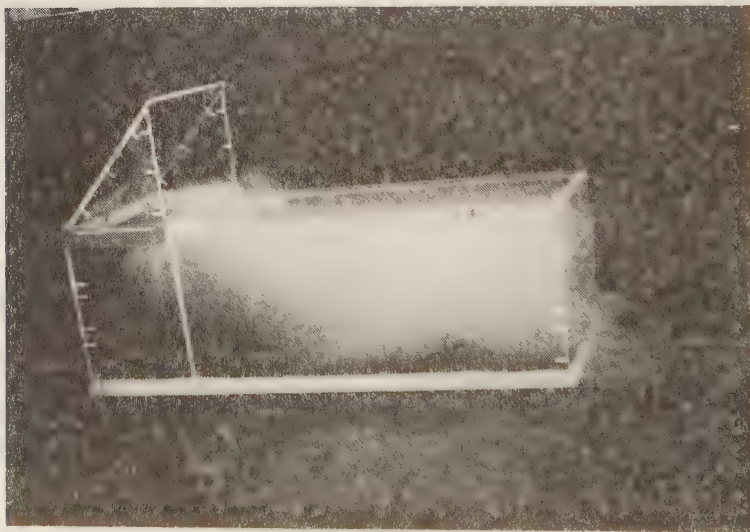
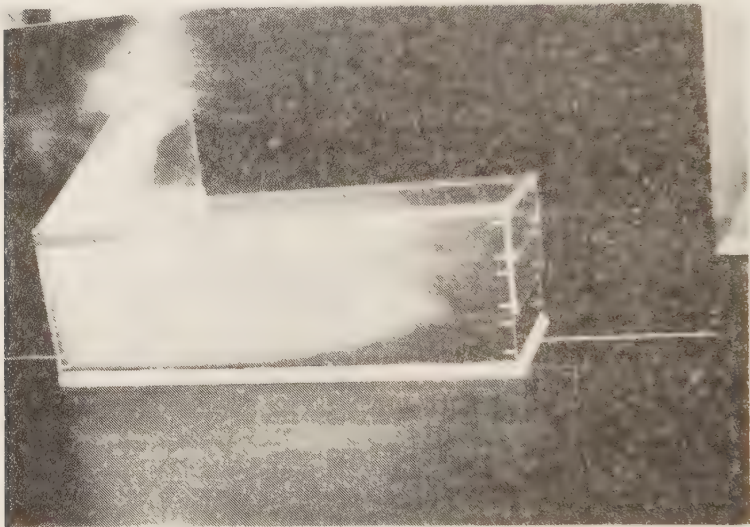
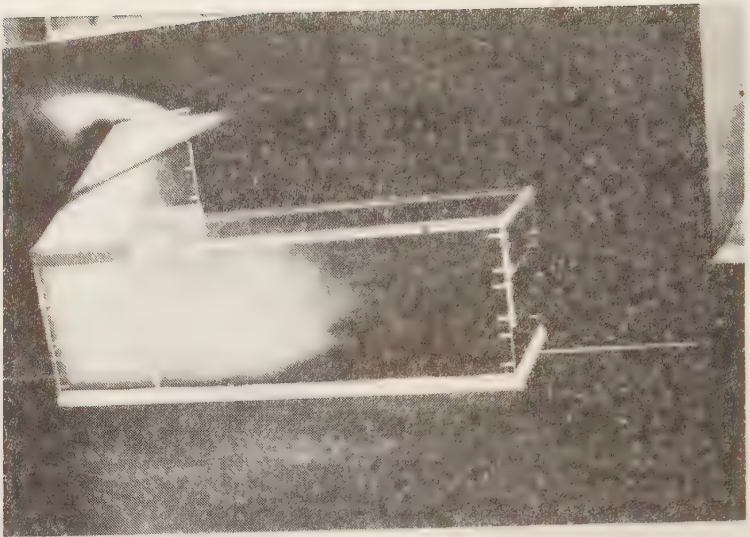


Figure 6.4.5 When the window is 1/3 area of surface wall the hot air under the ceiling removes slowly, but air movement reaches the occupants.

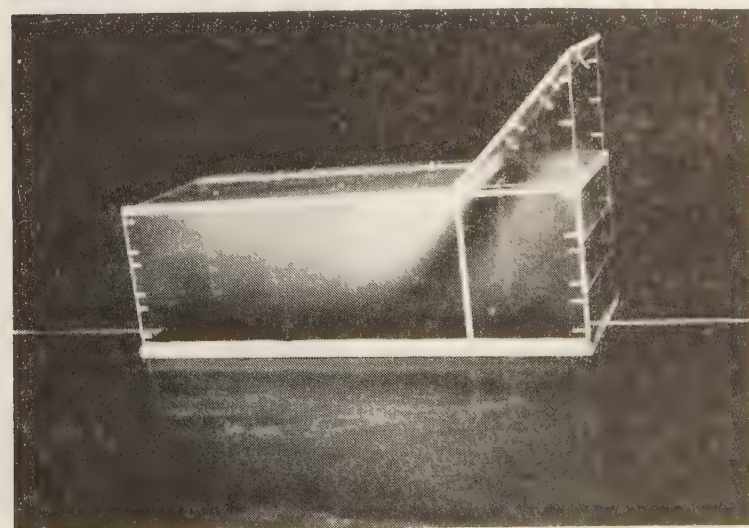
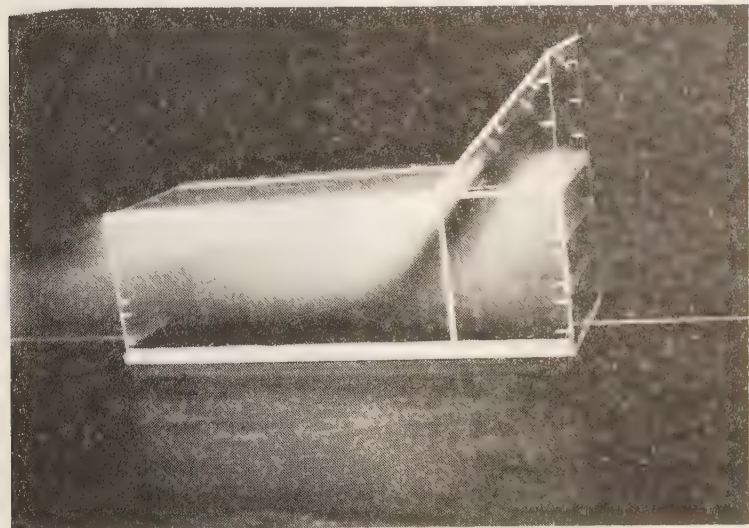
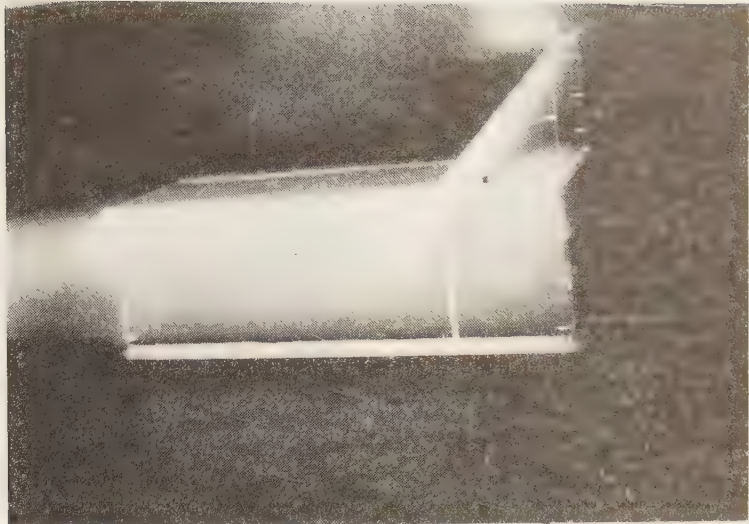
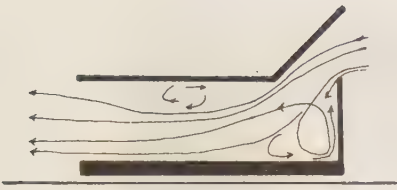


Figure 6.4.6 When the wind catch faces the prevailing wind and the window is on the opposite side of the room, the air flow above the floor is such that a person sitting in line with the opening will be cooled by air flow.

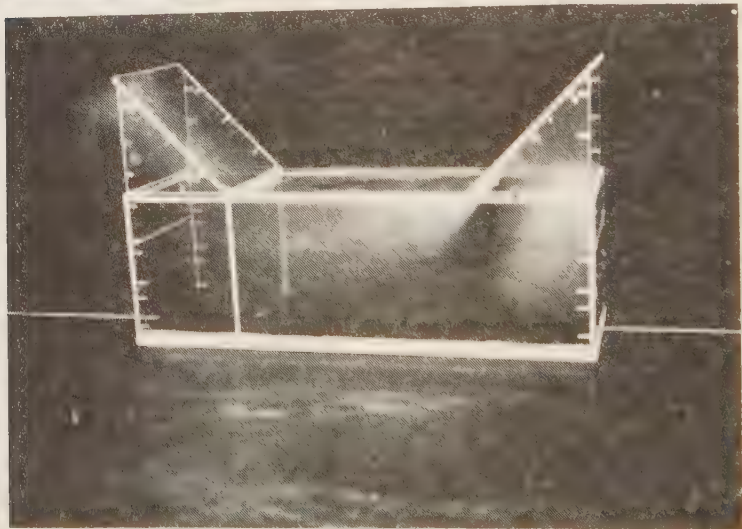
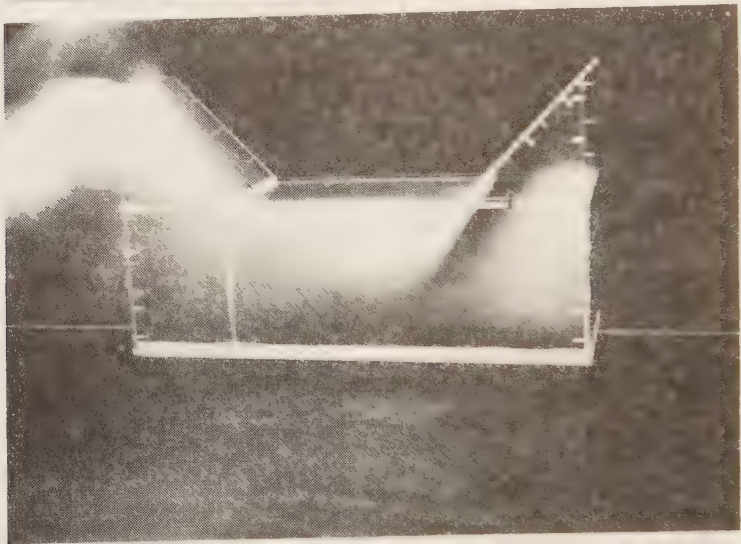
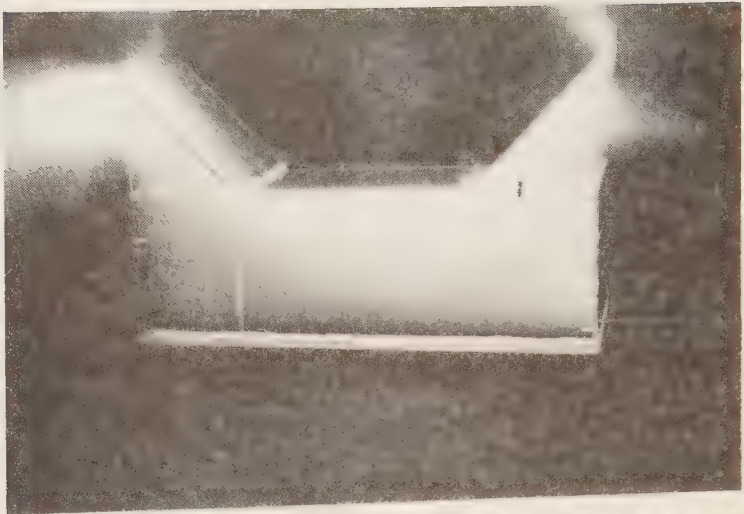


Figure 6.4.7 When the room has no window in the external wall, two openings can be made in the roof, one facing to the wind direction to let the wind in and the other in the low pressure area to let the air out.

so that the dust will be filtered out and the air humidified and cooled before entering the room through the window (Saini, 1973 and Oakley, 1961). Such devices are very useful for ventilation, but cannot be expected to create an air movement strong enough for physiological cooling, especially in hot aird regions with low wind speeds.

Evaporation of water needs a significant amount of heat, the latent cooling by evaporation at normal temperature is around 2400 kJ/kg of water (Koenigsberger and Ingersoll, 1974).

A system of evaporative cooling which is very successful in Egypt involves cooling the air directly in the occupant's space. The simplest form for cooling is achieved by frequent washing or sprinkling of the floor with water. This humidifies and cools the air by evaporation and at the same time reduces the surface temperature of the floor, which is in contact with bare feet, causing heat losses from the body by conduction.

The most commonly used air-cooling device in Egypt is the fountain, which is found in living-rooms in positions with high air movement. The air is deflected by the wind catch which projects above the roof level. This air looses heat first when it touches the cool floor and secondly by evaporative cooling, when it comes in contact with water. The rate of evaporation depends mainly on the difference between the vapour pressure of the air and the water. If the air is very dry, as in hot climate, the water will evaporate fairly rapidly. The air movement will also speed up evaporation.

When the fountain is in still air, there will be a layer of almost saturated air immediately above the surface of the water with a relatively high vapour pressure which will naturally tend to retard the process of evaporation. If this layer of moist air is continuously removed by air movement, evaporation will be accelerated. Therefore, it is very important to create movement of the air within the room. In old traditional buildings there are openings in the ceilings to remove hot air, which is replaced by cool air. In addition they created cross ventilation by an opening in the wall. Figure 6.5.1 and 6.5.2 below show the cooling process in the old traditional houses in Egypt.

6.5 AIR CHANGES BY NATURAL WIND

From equation (6.2.1), the approximate number of air changes per hour in the room in Figure 6.5.1 can be calculated. This room has been found in the house El-Sinnari (Figure 4.1.4). For the house Mohammed (Figure 4.4.3a and Figure 6.5.2) the air changes have also been calculated. The approximate dimensions of the room in Figure 6.5.1 are: 15 m long, 5 m height and 5 m wide with volume = 375 m^3 . The inlet opening is $2 \times 4 = 8 \text{ m}^2$.

Assuming that the natural wind forces producing ventilation are obtained at average wind velocity = 2.1 m/s according to available data for the city of Aswan, see Table 2.3.1. According to Ashrae (1970) we arrive at

$$Q = E \cdot A \cdot v$$

$$Q = 0.5 \cdot 8 \cdot 2.1 = 8.4 \text{ m}^3/\text{s} = 30240 \text{ m}^3/\text{h}$$

$$\text{Number of air changes/h} = \frac{30240}{375} = 80$$

With the room in Figure 6.5.2 room dimensions are 12 m long, 6 m height and 5 m wide with the volume = 358 m^3 . The inlet opening is $2 \times 3 = 6 \text{ m}^2$.

$$Q = 0.5 \cdot 6 \cdot 2.1 = 6.3 \text{ m}^3/\text{s} = 22680 \text{ m}^3/\text{h}$$

$$\text{Number of air changes/h} = \frac{22680}{358} = 64$$

Thus it is possible to achieve 50-100 air changes by natural wind if suitable openings and reasonable wind are available.

The observation above indicates that natural ventilation by wind force in a hot arid zone can give more than 50 air changes per hour.

6.6 INFLUENCE OF NIGHT VENTILATION

Table 6.6.1 shows the influence of different ventilation rates during the night when outdoor air is cool (less than 30°C). It can be seen

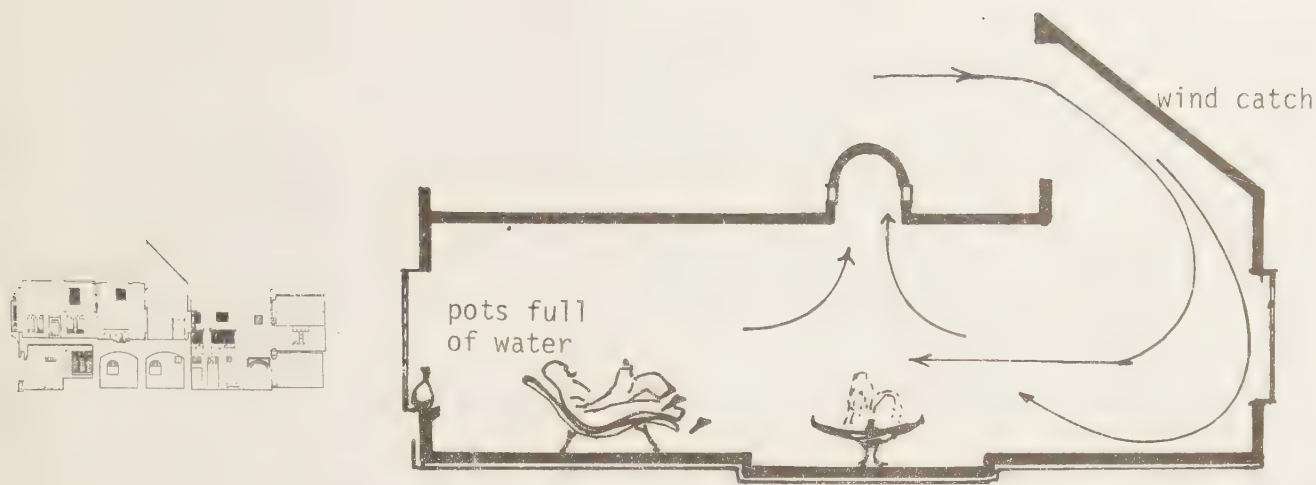


Figure 6.5.1 Summer room in house El-Sinnari

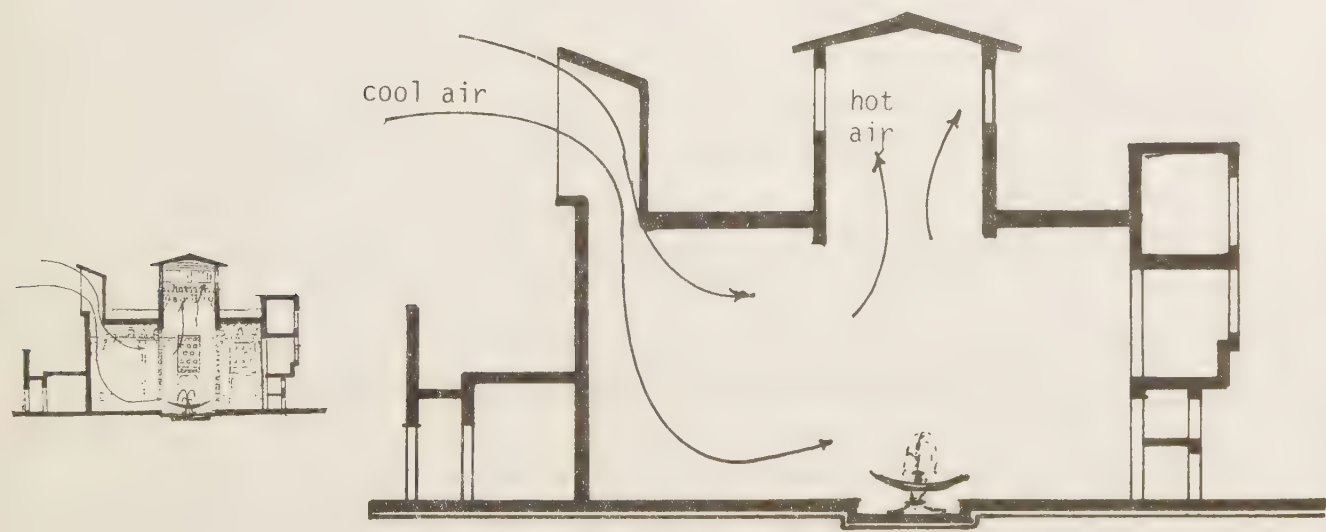


Figure 6.5.2 Summer room in house Mohammed

Table 6.6.1 Influence of number of air changes per hour on room air temperature in case of a roof made of 100 mm solid concrete slab with 50 mm mineral wool outside surface and different types of walls.

Time of day	Out-door air temp.	Room air temperature °C									
		wall made of 400 mm limestone					wall made of 50 mm mineral wool on outside surface of 216 mm red brick				
		number of air changes per hour					number of air changes per hour				
		0	10	40	80	160	0	10	40	80	160
01.00	21.9	39.1	30.9	25.7	24.1	23.1	38.3	29.2	24.8	23.6	22.8
02.00	21.6	39.1	30.5	25.3	23.7	22.7	38.2	28.9	24.5	23.2	22.4
03.00	22.1	39.0	30.5	25.4	23.9	23.1	38.1	28.9	24.6	23.5	22.8
04.00	23.6	38.9	30.8	26.2	25.0	24.3	38.0	29.2	25.5	24.6	24.1
05.00	26.0	38.8	31.4	27.7	26.8	26.4	37.9	29.8	26.9	26.4	26.2
06.00	29.0	38.7	33.9	30.9	30.1	29.6	37.8	31.6	29.0	28.3	27.9
07.00	32.5	38.6	34.0	31.2	30.4	29.9	37.7	31.7	29.2	28.5	28.1
08.00	36.2	38.5	34.1	31.3	30.6	30.1	37.7	31.9	29.3	28.7	28.3
09.00	39.7	38.4	34.2	31.5	30.7	30.3	37.8	32.0	29.4	28.7	28.4
10.00	42.7	38.4	34.3	31.5	30.9	30.4	37.8	32.1	29.6	28.9	28.5
11.00	45.1	38.3	34.4	31.8	31.1	30.6	37.9	32.2	29.9	29.2	28.9
12.00	46.6	38.4	34.4	32.0	31.2	30.8	38.1	32.4	30.0	29.4	29.0
13.00	47.2	38.4	34.6	32.1	31.4	31.0	38.2	32.6	30.2	29.6	29.2
14.00	46.8	38.5	34.7	32.3	31.7	31.3	38.3	32.8	30.5	29.9	29.6
15.00	45.7	38.5	35.0	32.6	31.8	31.4	38.4	33.0	30.6	30.0	29.6
16.00	43.9	38.6	35.0	32.7	32.1	31.7	38.5	33.3	30.8	30.2	29.8
17.00	41.6	38.7	35.2	32.9	32.2	31.9	38.6	33.2	31.0	30.4	30.1
18.00	38.9	38.7	35.4	33.2	32.5	32.1	38.6	33.4	31.2	30.5	30.2
19.00	35.9	38.8	35.5	33.2	32.7	32.3	38.7	33.5	31.2	30.6	30.2
20.00	32.8	38.9	35.5	33.5	32.8	32.4	38.7	33.6	31.3	30.7	30.4
21.00	29.8	39.0	33.7	31.1	30.5	30.1	38.7	32.3	30.3	30.0	29.9
22.00	27.1	39.1	32.8	29.3	28.3	27.7	38.7	31.3	28.5	27.8	27.5
23.00	24.8	39.2	32.0	27.8	26.5	25.7	38.6	30.4	26.9	26.0	25.4
24.00	23.0	39.2	31.4	26.5	25.0	24.1	38.5	29.8	25.7	24.5	23.8



Night ventilation from 2100 to 0600.

that when the wall of the room is made of 400 mm limestone and the room is unventilated, maximum room air temperature will be 38.9°C . When the room is ventilated by 10 air changes per hour during nights (2100-0600), the temperatures will be 35.5°C . By increasing the night ventilation to 80 air changes per hour, the maximum room air temperature will not exceed 32.8°C . Increasing the ventilation by more than 80 air changes per hour will not reduce room air temperature very much.

From Table 6.6.1 it can also be seen that when the wall is made of 216 mm red brick with 50 mm mineral wool placed on the outside surface and the room is ventilated at night by 80 air changes per hour, the maximum room air temperature will be 30.7°C .

This result shows that for this model and this climate, a suitable number of air changes per hour is about 100.

6.6.1 Influence of walls and roof

Table 6.6.2 shows that a room with a roof made of 100 mm solid concrete slab with 50 mm mineral wool placed on the upper surface has a lower indoor temperature than a room with a roof made of 200 mm solid concrete slab (larger thermal capacity). When the walls are made of 400 mm limestone and the roof is made of 200 mm solid concrete, the maximum room air temperature will be 34.4°C and mean room air temperature will be 30.2°C , but when the roof is made of 100 mm solid concrete slab + 50 mm mineral wool, the temperatures will be 32.7 and 29.2°C respectively. The table also shows that when the roof is made of hollow concrete with 50 mm mineral wool on the upper surface and the wall is made of 800 mm limestone, the room air temperature will be higher than that of a room with the same roof construction but the wall made of double red brick, 216 mm thick, with 50 mm insulation on the outside surface (Table 6.6.3). This result means that 50 mm insulation (high thermal resistance) placed on the outside of a homogeneous wall permits reduction of the thickness of the wall.

The result mentioned also means that a wall or roof constructed with high thermal capacity stores solar heat and consequently cools slowly.

Table 6.6.2

Comparison between indoor temperature with different types of roof and walls for rooms ventilated at night from 2100 to 0600 h with 100 air changes per hour.

Roof type	Wall of stone	Room air	Inside surface temperature °C											
			South				North				West			
			max	min	mean	max	min	mean	max	min	mean	max	min	mean
1		mm												
		200	39.0	23.6	31.0	38.6	27.5	32.1	39.4	27.6	32.4	40.9	28.0	32.8
		400	34.5	23.5	30.0	33.9	27.6	31.0	34.2	27.8	31.2	34.5	28.1	31.5
		600	33.6	23.3	29.7	33.1	27.1	30.6	33.3	27.2	30.7	33.5	27.4	31.0
11		concrete 100 mm	33.2	23.2	29.4	32.6	26.8	30.1	32.8	26.9	30.3	33.0	27.0	30.5
		200	38.7	23.6	31.1	38.5	27.5	32.2	39.3	27.7	32.6	40.8	28.0	32.9
		400	34.4	23.5	30.2	33.8	27.8	31.1	34.1	27.9	31.3	34.4	28.2	31.6
		600	33.6	23.3	29.9	33.0	27.2	30.7	33.2	27.3	30.9	33.5	27.5	31.2
3		concrete 200 mm	33.0	23.2	29.5	32.4	26.9	30.2	32.6	27.0	30.3	32.9	27.1	30.6
		200	37.1	23.4	30.3	37.5	27.2	31.6	38.2	27.3	31.9	39.7	27.7	32.3
		400	32.7	23.3	29.2	32.5	27.2	30.2	32.8	27.4	30.5	33.1	27.7	30.7
		600	31.8	23.1	28.9	31.5	26.6	29.7	31.8	26.7	29.9	32.1	26.9	30.2
6		+50 mm min. wool	31.1	22.9	28.4	30.8	26.2	29.1	31.0	26.3	29.2	31.3	26.4	29.4
		200	38.3	23.4	30.8	38.2	27.2	31.9	39.0	27.3	32.2	40.5	27.7	32.6
		400	33.5	23.3	29.8	33.2	27.4	30.7	33.5	27.5	30.9	33.7	27.8	31.2
		600	32.6	23.1	29.5	32.2	26.7	30.2	32.5	26.9	30.4	32.7	27.0	30.7
7		hollow concrete 280 mm	31.9	23.0	29.0	31.6	26.4	29.6	31.7	26.5	29.8	32.0	26.6	30.0
		200	37.8	32.4	30.6	38.0	27.1	31.7	38.7	27.2	32.1	40.2	27.6	32.4
		400	33.1	23.3	29.6	32.9	27.2	30.5	33.2	27.4	30.7	33.4	27.7	31.0
		600	32.1	23.1	29.2	31.8	26.6	30.0	32.1	26.7	30.1	32.3	26.8	30.4

outdoor air temperature: max=47.2 °C, min=21.6 °C and mean=34.4 °C

Table 6.6.3 Comparison between indoor temperature with different types of roof and walls made of 200 mm hollow brick, double hollow brick with 50 mm air space, single hollow brick with 100 mm mineral wool outside and between 50 mm air space, unventilated and double red brick with 50 mm mineral wool on outside surface.

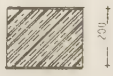
Roof type	Wall type	Room air temperature	Inside surface temperature °C																
			South			North			West			East			Ceiling				
			max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean		
 1	 1	37.9	23.3	30.4	37.7	26.6	31.4	38.2	26.7	31.6	39.2	26.9	31.8	38.3	26.7	32.0	37.3	29.8	32.9
		36.4	23.2	29.8	36.1	26.5	30.7	36.5	26.6	30.8	37.2	26.8	31.1	36.7	26.6	31.2	36.4	29.5	32.4
		32.7	22.9	28.4	32.3	25.8	28.9	32.4	25.8	29.0	32.6	25.9	29.1	32.5	25.8	29.1	34.5	28.7	31.2
 concrete 100 mm	 2	32.6	23.1	28.9	32.1	26.7	29.5	32.2	26.7	29.6	32.5	26.9	29.8	32.4	26.8	29.8	34.8	29.2	31.6

Table 6.6.3 (cont'd)

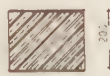
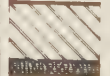
Roof type	Wall type	Room air temperature	Inside surface temperature °C																			
			South				North				West				East				Ceiling			
			max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean		
			37.0	23.1	30.1	37.1	26.3	31.1	37.6	26.4	31.3	38.6	26.6	31.6	37.7	26.4	31.7	35.8	29.2	31.9		
			35.3	23.0	29.5	35.3	26.2	30.4	35.7	26.3	30.5	36.4	26.5	30.7	35.9	26.3	30.8	34.6	28.9	31.2		
			31.2	22.7	27.9	31.0	25.4	28.3	31.1	25.4	28.4	31.3	25.5	28.5	31.2	25.4	28.5	31.5	27.8	29.2		
			31.5	23.0	28.5	31.1	26.3	29.0	31.2	26.4	29.1	31.5	26.5	29.3	31.5	26.4	29.3	31.9	28.4	30.1		
			31.5	23.0	28.5	31.1	26.3	29.0	31.2	26.4	29.1	31.5	26.5	29.3	31.5	26.4	29.3	31.9	28.4	30.1		
			31.5	23.0	28.5	31.1	26.3	29.0	31.2	26.4	29.1	31.5	26.5	29.3	31.5	26.4	29.3	31.9	28.4	30.1		

Table 6.6.3 (cont'd)

Roof type	Wall type	Room air temperature	Inside surface temperature °C											
			South			North			West			East		
			max	min	mean	max	min	mean	max	min	mean	max	min	mean
			35.4	23.1	29.5	36.0	26.3	30.6	36.5	26.4	30.8	37.5	26.6	31.1
			33.9	23.0	28.9	34.3	26.1	29.8	34.7	26.2	30.0	35.4	26.4	30.2
			30.0	22.6	27.2	29.9	25.1	27.6	30.0	25.2	27.7	30.2	25.2	27.8
3			30.6	22.9	27.9	30.3	26.1	28.5	30.5	26.2	28.6	30.8	26.3	28.8
	concrete 100mm +50 mm mineral wool													

Table 6.6.3 (cont'd)

Roof type	Wall type	Room air temperature	Inside surface temperature °C																
			South			North			West			East			Ceiling				
		max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean			
		36.4	23.1	29.4	36.6	26.2	30.9	37.2	26.3	31.1	38.2	26.5	31.3	37.3	26.2	31.5	34.9	28.4	31.3
		34.6	22.9	29.2	34.9	26.1	30.1	35.2	26.1	30.3	35.9	26.4	30.5	35.4	26.1	30.6	33.5	28.1	30.6
		30.5	22.6	27.5	30.3	25.1	27.9	30.4	25.1	27.9	30.5	25.2	28.0	30.5	25.2	28.1	30.2	26.8	28.7
																			
		30.9	22.9	28.1	30.6	26.1	28.7	30.8	26.2	28.8	31.0	26.3	29.0	31.0	26.2	29.0	30.7	27.4	29.4

Room ventilated at night from 2100 to 0600 with 100 air changes per hour. Outdoor temperature: max=47.2 °C, min=21.6 °C and mean=34.4 °C.

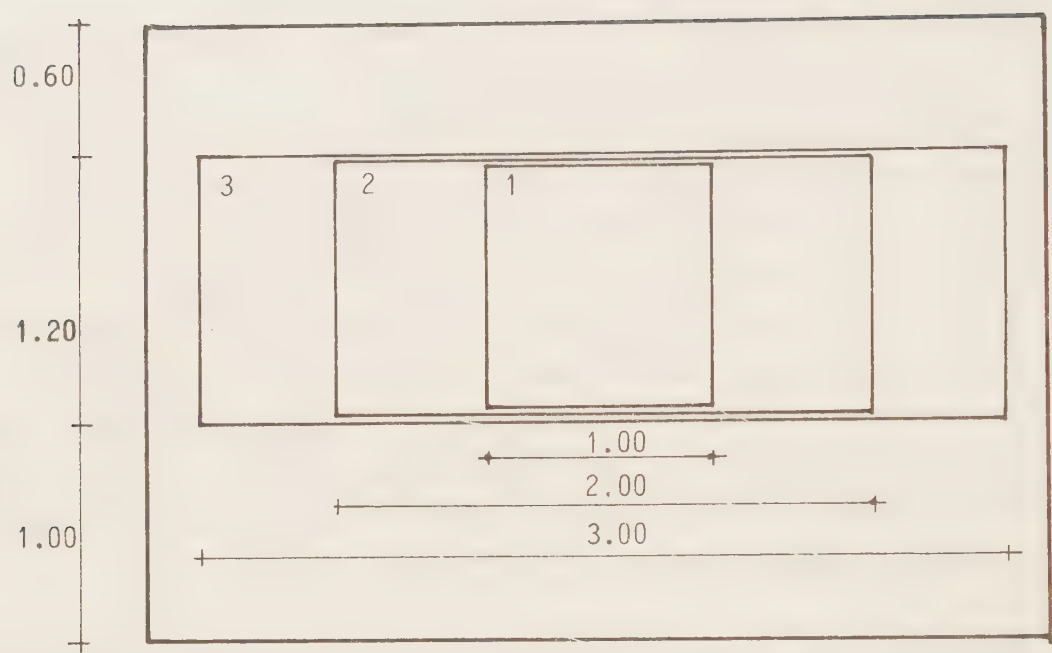
The construction should combine both thermal capacity and thermal resistance. This is emphasized by the results from Table 6.6.3, which shows a comparison between room with the same wall construction (single hollow brick with 100 mm insulation and 50 mm unventilated air space between brick and insulation) but with different roofs. When the roof is made of 100 mm solid concrete, maximum room air temperature will be 32.7°C but when the roof is made of hollow concrete, the temperature will be 31.2°C . When 50 mm insulation is added on the upper surface of the 100 mm concrete, maximum room air temperature of the room with solid slab roof will be 30.0°C , which is lower than that with a roof made of hollow concrete. This means that it is easier to achieve lower indoor temperature when the roof or wall has high thermal capacity and is covered with insulation externally than if the wall or roof is made only with massive construction.

Therefore it is important to night-ventilated buildings to design walls and roof with high thermal capacity inside and cover their outside surfaces with insulation. If insulation is not available, a hollow construction containing air should be used.

6.6.2 Influence of windows

From Figure 6.6.1 and Table 6.6.4, which show influence of window size and number of air changes per hour on indoor air temperature, it can be seen that with the room without window and unventilated, maximum room air temperature will be 38.4°C , but when the room has a window area = 1.2 m^2 and is ventilated by 10 air changes/h (average velocity = 0.13 m/s), maximum room air temperature will be reduced by 5°C to 33.6°C . By increasing the number of air changes per hour to 20 and increasing window area to 2.4 m^2 to get the same average velocity (0.13 m/s), the maximum room air will be 32.7°C , i.e. a reduction with 6°C compared with the case without windows and unventilated. This means that increasing window area and consequently increasing the ventilation rate can strongly reduce indoor air temperature.

It can also be seen from Table 6.6.4 by a comparison between a room with window area 3.6 m^2 and ventilated by 150 air changes per hour and



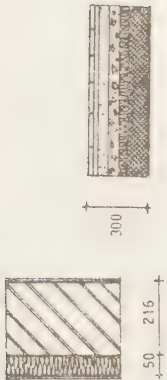
Window type	Window area m ²	Number of airch/h	Ventila- tion rate m ³ /h	Velocity m/s	Number of airch/h	Venti- lation rate m ³ /h	Velocity m/s
window 1	1.2	10	560	0.129	50	2800	0.648
window 2	2.4	20	1120	0.129	100	5600	0.648
window 3	3.6	30	1680	0.129	150	8400	0.648

night ventilation from 2100 to 0600 hour .

Figure 6.6.1 The north facade and window size.

Table 6.6.4 Influence on room air temperature of number of air changes/h and window size for windows facing north.

Time of day	Out-door air	no window and room unvent	Room air temperature at n air changes per hour					
			n					
			n=10	n=50	n=20	n=100	n=30	n=150
(h)	(°C)		window 1 (1.2 m ²)	window 2 (2.4 m ²)	window 3 (3.6 m ²)			
01.00	21.9	38.6	29.2	24.4	26.9	23.3	25.7	22.9
02.00	21.6	38.5	28.9	24.0	26.6	22.9	25.3	22.5
03.00	22.1	38.4	28.9	24.2	26.6	23.3	25.4	22.9
04.00	23.6	38.3	29.2	25.1	27.2	24.4	26.1	24.1
05.00	26.0	38.2	28.8	26.7	28.2	26.3	27.4	26.2
06.00	29.0	38.1	31.7	28.8	30.4	28.5	29.8	28.4
07.00	32.5	37.9	31.8	29.0	30.7	28.8	30.2	28.8
08.00	36.2	37.8	31.9	29.2	30.9	28.9	30.3	28.9
09.00	39.7	37.8	32.1	29.2	30.9	29.1	30.5	29.2
10.00	42.7	37.8	32.2	29.4	31.1	29.3	30.9	29.4
11.00	45.1	37.9	32.3	29.7	31.5	29.5	31.0	30.0
12.00	46.6	38.0	32.5	29.8	31.6	29.8	31.3	30.0
13.00	47.2	38.1	32.8	30.0	31.8	30.0	31.6	30.3
14.00	46.8	38.2	32.8	30.4	32.2	30.3	31.8	30.6
15.00	45.7	38.3	33.0	30.4	32.2	30.5	32.0	31.0
16.00	43.9	38.5	33.3	30.6	32.4	30.7	32.2	31.0
17.00	41.6	38.6	33.5	30.9	32.7	30.9	32.3	31.2
18.00	38.9	38.7	33.4	31.0	32.7	30.9	32.3	31.2
19.00	35.9	38.7	33.5	31.1	32.6	31.0	32.3	31.1
20.00	32.8	38.8	33.6	31.1	32.7	31.1	32.3	31.0
21.00	29.8	38.8	32.3	30.2	31.2	30.0	30.7	29.9
22.00	27.1	38.8	31.3	28.2	29.8	27.7	29.1	27.5
23.00	24.8	38.8	30.5	26.6	28.6	25.8	27.6	25.5
24.00	23.0	38.8	29.8	25.3	27.6	24.3	26.5	23.9



night ventilation from 2100 to 0600 hours.

another room with 2.4 m^2 and ventilated by 100 air changes (the average velocity is the same in both cases = 0.64), that the maximum room air temperature of the room with window = 3.6 m^2 is 0.1°C higher than that for the room with window = 2.4 m^2 .

6.6.3 Influence of shading external surface

Table 6.6.5 shows influence of shading of external wall surfaces (shaded from direct radiation according to the lower dimensions, but 50% shaded from diffuse radiation. See appendix B) and ventilation rate on indoor air temperature. It can be seen that in the case of a wall made of 216 mm brick with 50 mm mineral wool placed on the outside surface and with the room ventilated by 10 air changes per hour, maximum room air temperature will be 32.1°C and mean daily temperature is 30.5°C .

If the night-ventilation is increased to 80 air changes the temperature will be 29.8°C and 27.5°C respectively. This result shows that it is possible by night-ventilation of up to 80 air changes/h and external shading to reduce the maximum indoor air temperature to 29.8°C compared with the maximum outdoor air temperature, which reaches 47.2°C .

Table 6.6.5 Influence of shading of wall and ventilation rate on indoor temperature. The roof is made of solid concrete 100 mm thick with 50 mm mineral wool on top.



Wall type	airch. Room air per hour	Inside surface temperature °C											
		South				North				West			
		max	min	mean	max	min	mean	max	min	mean	max	min	mean
	10	32.1	28.0	30.5	32.0	29.7	30.8	32.0	29.7	30.9	32.0	29.7	30.9
	20	31.0	25.8	29.1	30.9	28.0	29.6	30.9	28.0	29.6	30.9	28.0	29.6
	40	30.3	24.1	28.1	30.1	26.7	28.6	30.1	26.7	28.7	30.1	26.7	28.7
	80	29.8	23.0	27.5	29.7	25.9	28.0	29.7	25.9	28.1	29.7	25.9	28.1
	160	29.8	22.3	27.1	29.5	25.4	27.7	29.5	25.4	27.9	29.5	25.4	27.7
	10	33.5	29.1	31.8	33.4	31.2	32.3	33.4	31.2	32.3	33.5	31.2	32.4
	20	32.5	26.7	30.3	32.4	29.3	31.0	32.5	29.3	31.0	32.5	29.3	31.0
	40	31.8	24.7	29.2	31.8	27.9	30.1	31.8	27.9	30.1	31.8	27.9	30.1
	80	31.3	23.3	28.5	31.3	26.9	29.5	31.3	26.9	29.5	31.4	26.9	29.5
	160	31.0	22.5	28.1	31.0	26.3	29.1	31.1	26.3	29.1	31.1	26.3	29.1

Night-ventilation from 2100 to 0600. Outdoor air temperature; max=47.2 °C, min=21.6 °C and mean=34.4 °C.

7 CONCLUSIONS

7.1 STRATEGIES

Maximum outdoor air temperature for summer conditions in Aswan, Egypt average 47.2°C at 1300 with a minimum of 21.6°C at 0200. Together with solar heat gain during repeated clear summer days we can expect very high indoor temperatures unless the building is properly designed and operated. The two strategies, which are strongly supported by the studies in chapter 5 and 6 are:

1. to protect the building against solar heat gain and penetration of high outdoor temperatures during summer days,
2. to cool the building with cool night air and store the cool in the building from the night to the day.

A third strategy which deals with winter conditions is:

3. to use solar heat gain during the winter in order to heat the building.

7.2 PROTECTION AGAINST HEAT GAIN

Firstly there is a heat gain by absorption of solar radiation in the outer surfaces of walls and roof. There are two approaches, either to reduce the amount of absorbed radiation or to make it difficult for the absorbed heat to penetrate walls and roof.

The influence of the external colour of the roof is shown in Table 5.3.9. It can be seen that the maximum room air temperature will be decreased as much as 2.1°C and the minimum room air temperature 1.8°C when the absorptivity is reduced from 0.8 (very dark colour) to 0.1 (extremely white). The very high temperatures are obtained because that

the room is unventilated. Similar results will be obtained by shading the roof.

The colour of the walls also has a large influence on the room air temperature. Table 5.2.27 shows that white hollow brick walls (200 mm) give 4.3°C lower maximum room air temperature than black walls. If the walls are heavily insulated the influence of the colour is obviously much lower (Table 5.2.28).

The effect of thermal insulation of the outer walls is shown in Table 5.2.10. With a solid, 216 mm thick, brick wall and unventilated rooms the maximum room air temperature will reach 41.9°C . With 100 mm of mineral wool insulation between two 108 mm brick walls the maximum room air temperature will be reduced to 39.4°C but at the same time the minimum room air temperature will increase from 36.8°C for uninsulated walls to 38.7°C for insulated walls. With night ventilation of the rooms with 5 air changes per hour 1900-0800 (Table 5.2.11) the maximum room air temperature will be reduced from 40.1°C for uninsulated brick walls to 36.3°C for walls with 100 mm mineral wool insulation.

Another way to protect against heat gain through walls is to create a wall with a ventilated cavity. Figure 5.2.18 shows the influence of such a ventilated cavity. With a permanently ventilated cavity the maximum room air temperature will be reduced 1.3°C . However, when the cavity is ventilated only during night the maximum room air temperature will be reduced 3.6°C . In both cases the cavity ventilation is assumed to take place with an air flow of about 0.6 m/s. This ventilation level necessitates mechanical ventilation. The wall outside the cavity is assumed to be made of 50 mm mineral wool, covered with metal net and stucco. As seen from Table 5.2.24 changing from normal wall material in the outside wall to mineral wool + stucco will for night ventilated cavities count for a decrease in maximum room air temperature of 1-2 $^{\circ}\text{C}$.

For the roof a reduction of the maximum room air temperature can also be achieved by thermal insulation. For an unventilated room 100 mm insulation will, according to Table 5.3.3 reduce the maximum room air temperature from 39.9°C (roof type 1: no insulation) to 39.2°C (roof type 3: 100 mm insulation). With a night ventilation level of 5 air

changes per hour 1900-0800 (Table 5.3.4) the maximum room air temperature will be 37.9 °C for the uninsulated roof (type 1) and 36.8 °C for the roof with 100 mm insulation (type 3).

Another strategy, which has been used in order to decrease the heat penetration from the outside is to increase the thermal capacity of walls or roof. As seen from Table 5.3.1 the effect of increasing the concrete roof thickness from 100 mm to 200 mm will not reduce the maximum room air temperature more than 0.2 °C. It will, however, raise the minimum room air temperature 0.3 °C.

Heat gain through windows is a very important part of the total heat gain. For unshaded windows the maximum room air temperature will be (Tables 5.4.2 and 5.4.3):

		Maximum room air temperature for a facade facing	
		South	West
No glass		39.9 °C	41.5 °C
Glass covering 1/3 of the facade		40.6	45.0
- " -	2/3 - " -	41.9	49.3
- " -	3/3 - " -	42.9	52.9

A large west facing unshaded window is obviously a disaster for the room climate. A south facing window, however, will only slightly increase the room air temperature during summer days. West and east oriented windows must be shaded but south oriented windows can be left unshaded or only partly shaded. A north oriented unshaded window is worse than a south window at this latitude (Figure 5.4.1). It is, of course, better than west or east oriented windows.

7.3 COOLING BY NIGHT VENTILATION

Night ventilation of room will use the cool outside evening air to cool the room interior and then store this cool for the following day when the room is left unventilated. We need both night ventilation and indoor storage capacity. This is clearly shown in Table 5.2.6 where

different ventilation strategies are compared. The maximum and minimum room air temperatures (RAT) are:

	Outer walls made of			
	100 mm limestone		400 mm limestone	
	max RAT	min RAT	max RAT	min RAT
Unventilated rooms	45.3°C	33.1°C	39.8°C	38.6°C
Permanently ventilated rooms, 2.5 airch/h	44.2	30.8	40.1	34.7
5. airch/h	44.9	30.7	41.0	32.3
Night ventilated (1900-0800) rooms,				
2.5 airch/h	44.1	29.3	38.2	34.4
5. airch/h	44.7	29.1	37.6	31.9

It is quite obvious that the rate or mode of ventilation will not influence the maximum room air temperature for a house with walls made of 100 mm limestone. The minimum room air temperature will decrease with increased ventilation.

For a house with 400 mm limestone walls permanent ventilation will increase the maximum room air temperature compared with unventilated rooms but decrease the minimum room air temperature. Night ventilation has a good effect both on maximum and minimum room air temperatures.

The important conclusion here is that night ventilation must be combined with a sufficient interior storage capacity.

In Table 6.6.1 the influence of large numbers of air changes per hour during nights (2100-0600) is shown. For a house with outer walls of 216 mm red brick, insulated on the outside with 50 mm mineral wool and covered with a metal net and stucco, the maximum and minimum room air temperatures are:

	Max. room air temperature	Min. room air temperature
Unventilated	38.7°C	37.7°C
Night ventilated (2100-0600)		
10 airch/h	33.6	28.9
40 airch/h	31.3	24.5
80 airch/h	30.7	23.2
160 airch/h	30.4	22.4

Normally, night ventilation with 5-10 air changes per hour can be obtained in hot arid zones by using only the stack effect together with sufficient large inlet and outlet openings. However, it is obvious that more than 40 air changes per hour during night result in reasonable room air temperatures if the house is suitable designed and ventilated by natural wind forces.

7.4 DESIGN RULES

The following rules of thumb can be abstracted from the above studies.

1. Use night ventilation caused by natural wind and/or stack effect.
2. Use shaded windows facing normal wind direction or wind catches for night ventilation by natural wind.
3. Use south oriented windows, which can be relatively large.
4. Use either outer walls made of 300-400 mm limestone or other local material or 200 mm brick insulated with 50 mm insulation on the outside and covered with metal net and stucco.
5. Use at least 50 mm insulation in the roof.
6. Increasing the thermal capacity of roof and walls will have little effect on heat penetration, compared with increased thermal insulation.
7. Use white colour on the roof and wall surfaces or shaded walls - if darker colours are desired there because of glare, use insulation in the walls (if possible).
8. Use concrete or other materials with good thermal conductivity and large storage capacity in the floor. In winter they can be covered with carpets.

These rules of thumb will not contradict the traditional design described in chapter 4. However, new building materials as thermal insulation can improve traditional design motifs.

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APPENDICES

APPENDIX 1

Summer-day weather data for Aswan

Time of day (h)	Out- door air temp. (°C)	Solar radiation intensity (W/m ²) on surfaces facing				
		South	North	West	East	Roof
01.00	21.9					
02.00	21.6					
03.00	22.1					
04.00	23.6					
05.00	26.0					
06.00	29.0	40.51	243.8	40.52	571.7	151.4
07.00	32.5	84.91	296.2	84.20	809.1	389.1
08.00	36.2	122.9	277.6	119.4	842.0	611.6
09.00	39.7	153.1	242.2	146.5	758.2	797.6
10.00	42.7	175.1	208.8	165.8	598.8	936.3
11.00	45.1	189.3	188.3	179.8	391.7	1019.
12.00	46.6	201.9	191.2	223.0	190.2	1043.
13.00	46.2	185.8	191.6	449.8	175.7	1003.
14.00	46.8	170.1	216.8	646.7	161.5	904.8
15.00	45.7	145.9	251.6	789.0	140.1	752.6
16.00	43.9	133.5	285.6	847.0	110.9	555.8
17.00	41.6	73.57	292.8	771.4	73.41	326.0
18.00	38.9	28.27	209.0	468.1	28.24	96.25
19.00	35.9					
20.00	32.8					
21.00	29.8					
22.00	27.1					
23.00	24.8					
24.00	23.0					

APPENDIX 1.1

Maximum and total solar intensity on surfaces

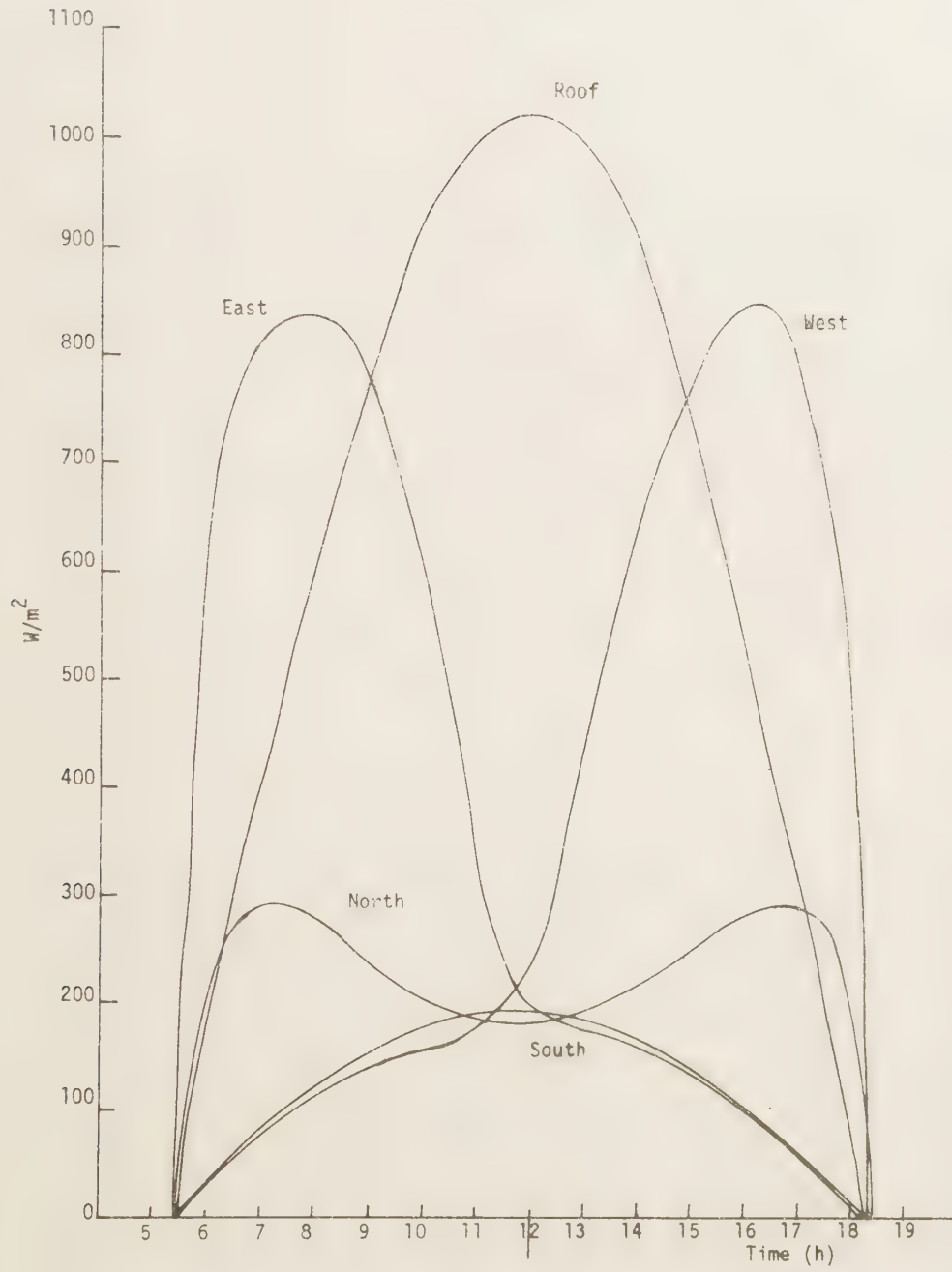
Maximum solar intensity (W/m ²) on surfaces facing					Total daily solar intensity (Wh/m ² ,day) on surfaces facing				
South	North	West	East	Roof	South	North	West	East	Roof
201.9	296.2	847.0	842.0	1043.	1685.	3095.	4930.	4852.	8588.

Outdoor air temperature, °C

Maximum	Minimum	Mean
47.2	21.6	34.4

According to Climatological Normals (1938),
Outdoor air temperature reaches maximum between
13-14 hour (local time) and minimum between 02-03
hour (local time).

APPENDIX 1.2



Solar radiation intensity on different surfaces.

APPENDIX 1.3

Shape factors for model 1

	South	North	West	East	Roof	Floor	Window	Door
South	0.000	0.097	0.170	0.202	0.268	0.250	0.013	0.000
North	0.090	0.000	0.187	0.187	0.255	0.261	0.000	0.019
West	0.113	0.134	0.000	0.177	0.264	0.264	0.014	0.035
East	0.134	0.134	0.177	0.000	0.264	0.264	0.014	0.013
Roof	0.125	0.128	0.185	0.185	0.000	0.339	0.018	0.021
Floor	0.117	0.131	0.185	0.185	0.339	0.000	0.015	0.029
Window	0.100	0.000	0.163	0.163	0.302	0.251	0.000	0.021
Door	0.000	0.100	0.256	0.099	0.222	0.310	0.013	0.000

Distribution factors for model 1

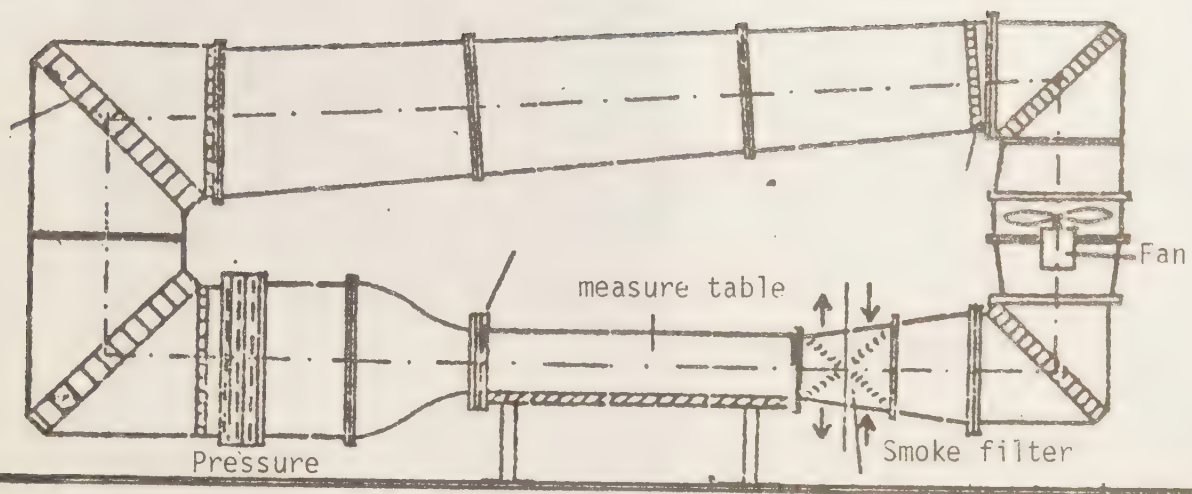
	South	North	West	East	Roof	Floor	Window	Door
South	0.059	0.085	0.126	0.133	0.183	0.385	0.017	0.012
North	0.080	0.063	0.130	0.130	0.180	0.389	0.012	0.016
West	0.084	0.093	0.088	0.127	0.181	0.390	0.017	0.019
East	0.089	0.093	0.127	0.089	0.182	0.389	0.017	0.015
Roof	0.085	0.090	0.127	0.127	0.124	0.411	0.018	0.016
Floor	0.090	0.097	0.136	0.136	0.206	0.297	0.019	0.019
Window	0.082	0.063	0.125	0.125	0.190	0.387	0.012	0.017
Door	0.057	0.085	0.143	0.109	0.171	0.405	0.017	0.012

APPENDIX 2

Thermal properties of building materials (Dreyfus, 1960)

Material	Conductivity λ W/m, °C	Specific heat c Wh/°C, kg	Density ρ kg/m ³
Foam concrete	0.314	0.29	600
Plaster	0.697	0.217	1800
Red brick	1.002	0.229	1952
Concrete	1.44	0.278	2403
Asphalt	0.743	0.253	2112
Sand	0.323	0.221	1513
Mortar	0.697	0.26	1800
Cement tile	0.697	0.217	1800
Ordinary concrete	0.697	0.217	1800
Back filling	0.323	0.221	1513
Limestone	0.933	0.251	1648
Hollow red brick	0.484	0.255	1184
Expanded polystyrene	0.034	0.460	50
Wood fibre	0.197	0.395	800
Mineral wool	0.058	0.220	450
Hollow tile slab	0.484	0.255	1184
Wood	0.140	0.390	974

APPENDIX 4



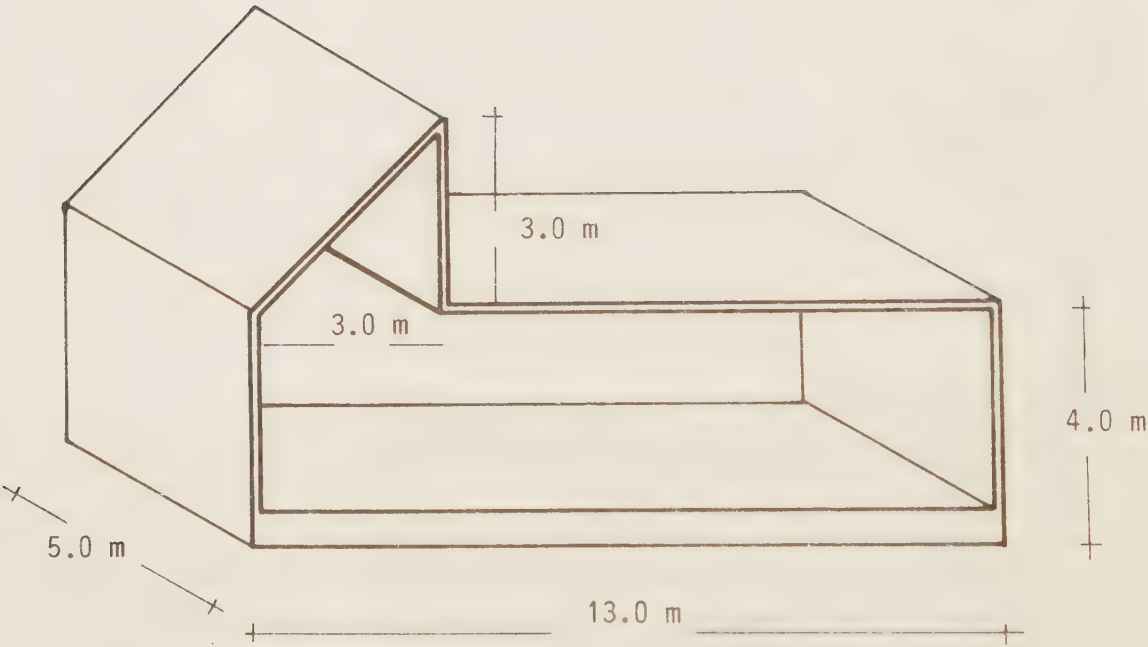
Wind tunnel

- 1) Wind speed can be regulated from 0-13 m/s
- 2) Measurement: width = 1.6, height = 0.4 and length = 1.9 m

Method of the test

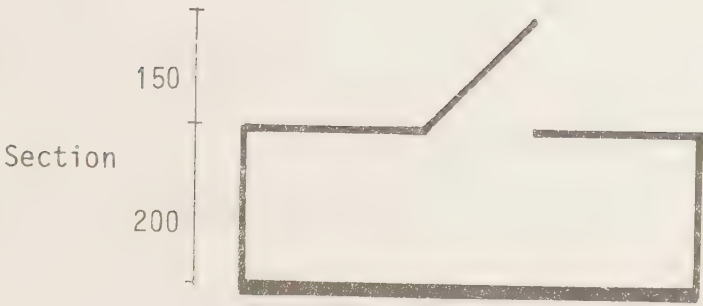
- The smoke from titanium tetrachloride was used to test air flow patterns in the model.
- Different wind speeds have been tested in the model, varying from 0.1 m/s to 5 m/s. However, the reasonable wind speeds used are: 0.5 and 1.0 m/s.

APPENDIX 4

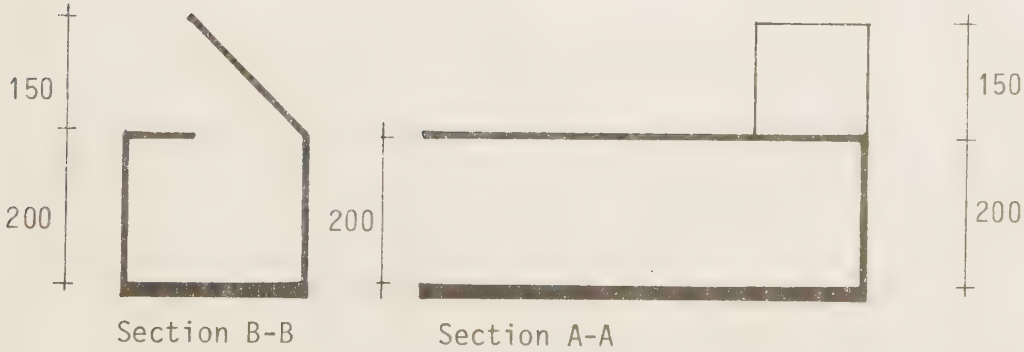
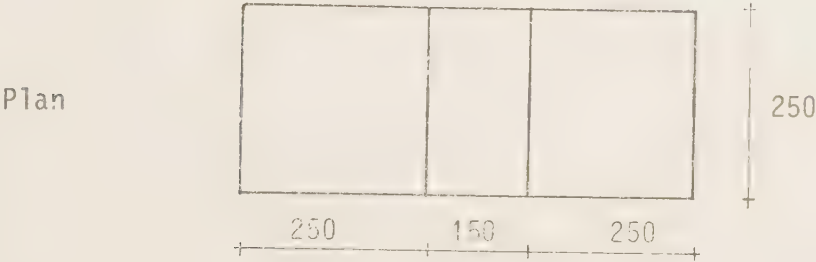


Scale 1:20

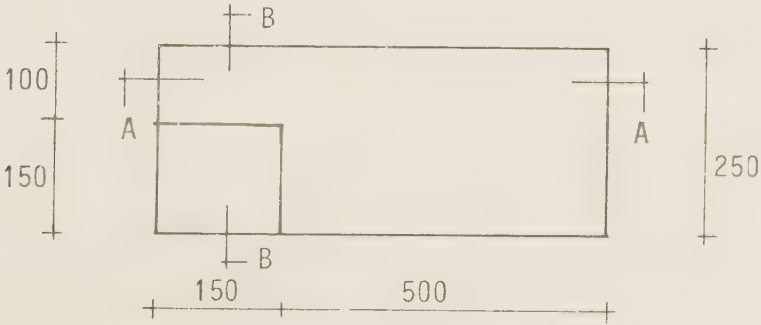
APPENDIX 4.1



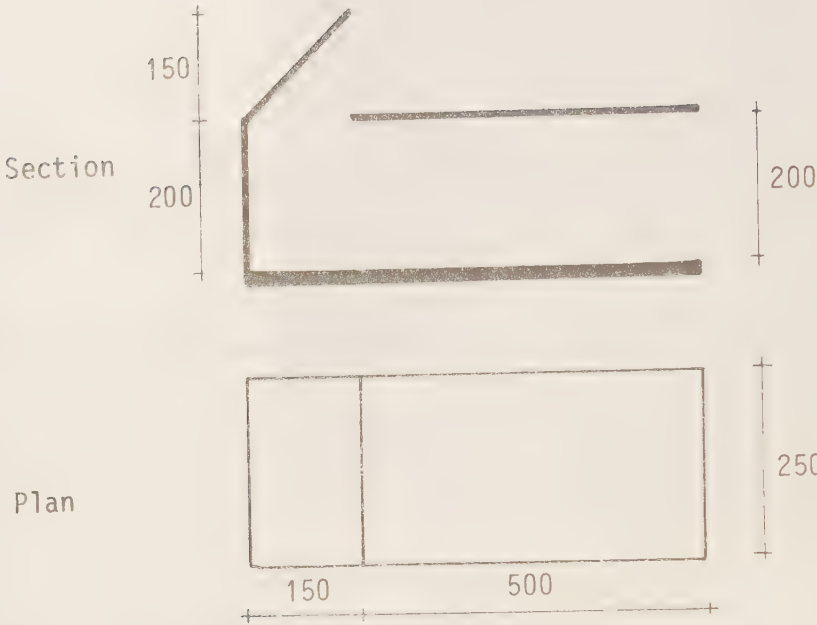
Model 1



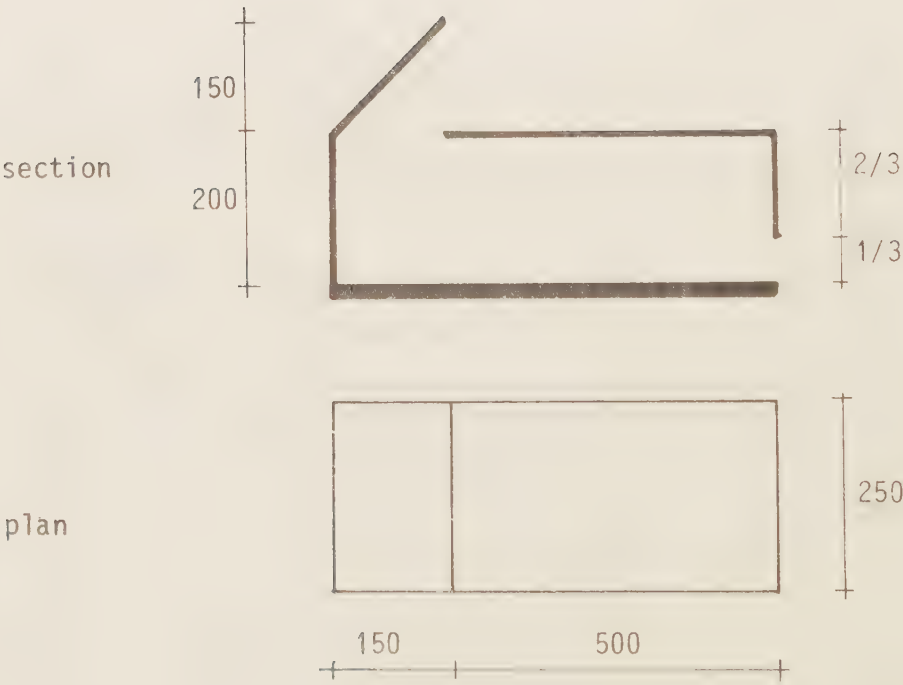
Model 2 plan

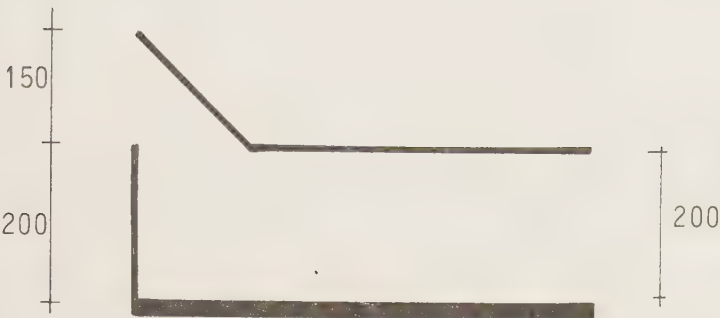


Model 3

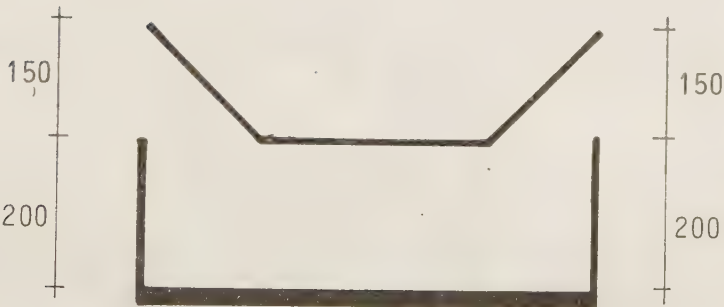
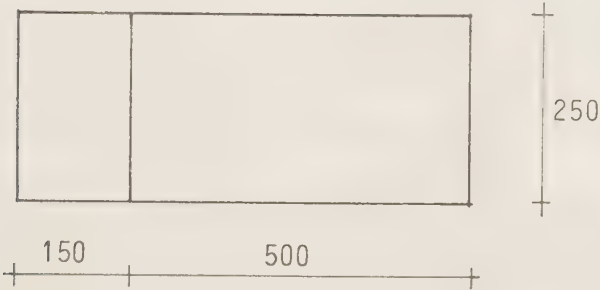


Model 4

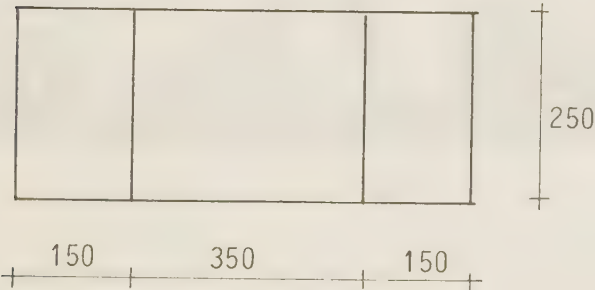




Model 5



Model 6



APPENDIX 4.2

